A HISTORY OF FIRE AND FLAME

A SALAMANDER LIVES IN THE FIRE
WHICH IMPARTS TO IT A MOST GLORIOUS HUE.

This is the Reiteration, gradation, and amelioration of the Tincture, or Philosophers' Stone; and the whole is called its Augmentation.

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A HISTORY OF FIRE AND FLAME

BY

OLIVER C. de C. ELLIS

Sometimes hee sayd I should write a great Historie:
Sometimes againe hee sayd that I should devise an incredible tale,
—Adlington's *Apuleius*.

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To
RICHARD VERNON WHEELER

I had dallied with the idea of some sound sonorous Latin and indeed I had already verified the quantities of PRÆ-CLARISSIMUS and of PYROPHORUS—which, I admit, is Greek: but in the world we live in, Leisure has covered her face; and many readers might delay to read in Latin what I have here written in a yet nobler tongue in qualification of the audacity of my title.

The audacity of supposing that you yourself will find the time to read my book remains. Yet I hope that you will read it.

I have tried to trace the development of a few ideas, and I think it is by the resulting map of this voyage of exploration that my book should stand or fall. If it is not in clear relief, then I have failed; for it has been my ambition to offer a stereoscopic view to readers who have been too thoroughly habituated either to the single lens of "Science" or to the single eye of the "Arts". The detail is to be regarded not as encyclopædic—that seems to be neither desirable nor feasible—but as illustrative. Such detail as I have employed has not been wrested to fit my deductions and conclusions, nor have I rejected any detail—I know of none—that fails to support them. I have at least been loyal to that genius of research which offers a patient welcome to an apparently inimical datum and finds therein the key to some rich field of new discovery. I have re-cast and reconstructed until I have lost count of my new beginnings. The task has possessed the fascinating irksomeness of a schoolboy's problem or of a jig-saw. Now the puzzle is complete; the sum is right; and I hardly know whether to be glad or sorry that the work is done.

OLIVER C. DE C. ELLIS.

MANCHESTER,
THE UNIVERSITY UNION.

PREFACE.

IT is said that a spirit, returning to Nonentity after a brief sojourn in Existence, was asked by his stay-at-home relations whether the visit had been a success. Yes, he said; it had surpassed all expectation. "But is it not rather a troublesome business, this Existing?" No question of that, he said. "And you found it worth while?" Why, he said, to know Fire alone is worth all the trouble of Existing. "And what is Fire?" —But he could not explain Fire to those who had never Existed.

And we—we who have the remarkable privilege of existing in the world where Fire lives—we who are Fire's co-partners in Existence—can we explain Fire? As well explain ourselves! But do we even realize the power of Fire in our world, the power of the idea of Fire in our minds? Well, we can realize something of that now, at any rate, now that we have Dr. Ellis's *History of Fire and Flame.*

This history is the work of one who is both scientist and poet; and thus it includes in its rich and vivid discussion the twofold majesty of Fire—its majesty in material events, and its majesty in the thought of man. For the first time, I believe, with anything like adequacy, an account has been written of this noble element of man's experience, from primitive awe, through fantastic speculation and profound symbolism, down to Dr. Ellis's

own beautiful experiments in the fiery nature of things. But Dr. Ellis knows too much about Fire, and too much about its congener, the mind of man, to mistake the various aspects of this grand experience of ours for distinct compartments of Existence. Infinitely various, it is yet all One. Here we exist, and with us in this world exists Fire. Wonder, speculation, symbolism, experiment—these are the different faces of the mystery that we dwell here side by side with, Fire. Fact and feeling, knowledge and imagination—Dr. Ellis has written the history of them all: for all equally unite in man's experience of Fire.

LASCELLES ABERCROMBIE.

CONTENTS.

[and see page 33.]

CHAPTER III.

THE PRIMAL MATTER.

CHAPTER IV.

THE BAND OF UNION.

CHAPTER V.

THE SPIRIT IN PRISON.

CHAPTER VI.

NATURE'S TWO HANDS.

CHAPTER VII.

ALL AIR AND FIRE.

CHAPTER VIII.

THE BLOOD OF THE SALAMANDER AND THE PHILOSOPHER'S STONE.

CHAPTER IX.

MR. PICKWICK AND NEIGHBOUR SEA-COLE.

CHAPTER X.

THE QUIVERING MANE.

LIST OF ILLUSTRATIONS.

CHAPTER I.

THE MEDIUM OF EXCHANGE.

This Proteus of Matter, being held by the sleeves, will turn and change into many metamorphoses.
—*Sylva Sylvarum.*

He transforms himself into all the wondrous shapes in Nature: Fire, a Savage Warrior, and a Flowing River.
—*Georgics.*

As Gold is given for everything, and everything for Gold, Fire is the general medium of exchange.
—*Heracleitos.*

§ 1.

Man's first consciousness was of One, and ever and again in the spiral progress of his history he returns to a consciousness of One. At each return, it is to a higher conception. The steps range imperceptibly from the extreme limit of an unanalysed and confused unity to another extreme limit, one of integration that for the present we must be content to imagine. To primitive Man, it was a primitive conception, the starting-point of a differentiation. To us, it is the goal of a synthesis.

As he moved among the rhythms of existence, primitive Man saw twos, and then he saw threes. But the twos came first, for these the cattle know. There is a sense of balance and antithesis that breeds in the intelligent animal a conscious or unconscious dualism. He goes and returns, fasts and eats, is uneasy and at rest, knowing light and darkness, male and female, heat and cold. The backward child, pressed to definition by

paraphrase, still resorts to the antithetic negative: "bad" is "not good". There are things above (him) and things below (him), for to the undeveloped mind self-importance is an axiom too obvious for formulation. Thus also man found that there were matters on his left hand and other matters on his right. Philosophy taught later that virtue was a straight line lying between the lovely sinusoids of vice, but the animal steered his Middle Way not among vices but between perils.

§ 2.

So it was that dualism led to the triads. The danger on the left was opposed to the danger on the right, and each in turn, or even together, was opposed to safety. This point will be found recurrent in our history. For example, the water-snake was opposed in thought not only to the phœnix but also to the fiery serpent; and any of these, separately or in concert, were opposed also as well to a life that was not self-renewing as to a restful calm. Thus also the extremes of red and blue, connoting among other ideas those of corrosive heat and cold venom, balanced about the happy mean of white or the unhappy mean of black, the one a blessed restfulness, the other an imposed impotence, but both passive however much they might be opposed as to luck, beneficence, purity or good cheer. And here we come to Fire and Water, with their relatively passive intermediates, wood and wine, blood and vapour, and ash—which was Salt. Fire, Salt and Water will run like a triple thread of Red and White and Blue through every episode of our narrative.

§ 3.

A short perspective of the history of thought must not claim to be more. To synthesise the simple impressions and innumerous concepts of primitive man would be to rebuild a shattered globe of clouded crystal from its shards and atoms. He himself could hardly synthesise matters that had not yet been subject to analysis. The communal feeder of the modern city consciously relates food and fuel, perhaps even counts up his calories: his ancestor made no distinction between them. After the wine, he may permit himself a sententious cliché about fire and life: "Whatever lives is fire" says Paracelsus: his ancestor identified them merely because he had never separated them. From the tree came clothing, bedding, food and fuel, and worship returned to it as to the source of life and fire. Some trees yielded a blood or milk. These were the object of especial veneration. The milk concreted in a cheesy gum, and this was offered back again as incense, not only to the tree but to other manifestations of the mind of the Being on whose breast or back Man lived; for, since life was communicated from the spine, he worshipped the spine-like mountain-ridges and set up great monoliths as tokens of the backbone. But the sign of Life was Motion: he identified Life with Motion; he worshipped the fountain, the river and the wind. All about him, the energy-reservoirs of the Universe ran to waste: he peopled the World.

§ 4.

If moving things were the habitats or the engines of spirits, spirits might also exist alone as their separated

essential life. Since dead men had ceased to breathe, the life was the breath and breath was the steam of fire and water. Loss of blood was loss of the inward fire, the source of breath. So also the blood was the life, but it did not survive life as the breath seemed to do. On a still day, the tenuous tail of some high isobar, dragging idly through the tranquillity of the lower atmosphere, would catch up a few leaves in an eddying spiral and pass on. The man had seen a similar outline in the smoke of his fire and in the growth of certain parasitic woody plants, the ivy, the vine and the mistletoe. Sometimes it moved as the sun did; sometimes it moved "widdershins" : and this variation was the basis of one of the most ancient forms of augury. Fern-fronds were coiled like that. His dog moved in that manner before settling down to sleep. So did the peacock before rain. The points of light in the night-sky moved like that. The whorled shell that whispered, held to his ear, it too was shaped like that. The necks of flying things, the crane, the heron, the ibis, the wild-goose—they were like that. He worshipped this little spirit which had thus transiently appeared to him, and with a piece of red ochre he daubed upon the wall of his cave the sacred spiral. The red was for fire. He found a living spiral in the serpent, and invented the dragon. Now just as cold and heat were both, as energy, in the same category, yet within that category opposing poles, so fire and water were linked as the necessary agents of life and yet destructive one of the other. Thus the spiral might now be significant of something that was hot, or might become hot, now representative of something that was cold, or might create cold, but never of anything that was inert. The earliest

tendency seems to have been to connect the serpent with good and with health, as when the Mexican rain-gods, the boat of the Egyptian Sun-god and the Hebrew fiery seraphim were all depicted as serpents. Quite late, there was the serpent of Epidaurus that followed Æsculapius to Rome. Yet, side by side with this, there grew up an association of the serpent with activities that were malevolent, and there were ideas of neutral sense also, as in the myth of a Worm called Schamir or Thumare which could cut through the hardest stone, or as in the prevalent belief that serpents originated from the human intestine, the inner hearth of the body. Aeons later, the surviving spirit of the wicked dead was described as "a worm that dieth not, a fire that is not quenched", and in pious keeping with this foul image was our recent national practice of disembowelling the poor wretch condemned for petty theft or for "heresy" and burning his entrails before his dying eyes.

§ 5.

Sometimes these little eddies spun along for a considerable distance, but they were always deflected from the surface of the earth by energy-sources—by a fire, or by a running stream—and this observation was later to bear fruit in the demonology of folk-lore. As Paracelsus puts it, "The life of water is its flowing", and this conferred its sanctity, a sanctity quite independent of any formal acknowledgment of "sacred rivers" and "holy wells". No effect of witchcraft might persist if it crossed a stream. It was often the spring that consecrated the tree-bordered grot in which it bubbled, and its gentle nymph was the presiding spirit of the attendant grove.

Thus among the Egyptians, the sign for running water was simply—the serpent.

There were great and powerful spirits also. They uprooted trees and carried them up and along invisible spiral airways. They appeared over the sea. They sucked the clouds into huge cornucopia in which Egypt was to recognise the nourishing bosom of the Sky-goddess. As sandstorms, they rode the desert. These spirits were fire—or, as later folk-lore was to have it, were "made of" fire. "The Lord answered Job out of the whirlwind". One of the later persistent echoes of such a belief is to be found in the *Arabian Nights* where the Efrits (which were made of fire) join in conversation, one with another, and then "resume their appointed circuits".

§ 6.

As the spiral wind left the red ember, or the glowing flame swept the green leaf, it left a charred black or a white ash. The man found these colours of red, white and black in soils, in the furs and skins of beasts, in the hair and complexion of men and in the feathers of birds. Found in birds, they immediately related to fire, for their flights were the haunts of free spirits, and only as to the head did spirits differ from birds even in form. A later sophistication admitted the connection between colour and thermal condition in other objects: to the ancient Egyptian, for example, the north was red, and the northern stars were sacred, since from the north came the refreshing Mediterranean wind, blowing from the nostrils of the Creator to revivify the dead Osiris: but even the cave-men seem to have thought that red earth would revitalise the dead. As for the sterile southern wind,

that was "leaden", even so late as Horace. Plumages formed a ready basis for explanatory myths of the recovery of lost fire—for in every mythology there is this trace of some frozen period when the preservation of fire had been neglected, a period only ended by the painful or magical discovery of its sources. Some bird was often the Mercury that brought it back, and in Yucatan, the Fire-bird was identified even with the Sun-god himself. Philostratus believed that the Arabs obtained oracles from the birds, first learning their language by the simple process of dieting themselves on the heart or liver of serpents. This is to identify the bird with the serpent, the justification being that each is identified with Fire.

There was also a beast whose relationship to fire seemed clear. It was the ancestor of Pegasus and of the steed that strode in its hour over garments and palm-branches from Olivet to Jerusalem. It was the wild ass that snuffeth up the wind in the desert. It was the very proverb and symbol of speed. To the Egyptian it was one of the representations of Osiris, golden and divine. It so impressed the lively and sensitive intelligence of the Zoroastrian that he regarded it as the especial and peculiar creation of Ormuzd. Now, as we have already noted, the more penurious the vocabulary, the less possible is distinction between things that are akin. Because his heels were speedy, they were cinnabar-red. Because he was wild and untamable, his head was of the colour of anger. The savage said of his mount, as the Elizabethan said of his, that he was all air and fire; but the savage said it more picturesquely by creating in his imagination a firebrand flaming at the splendid brow. And so, in the time of Ctesias, men believed in a race of horses having

a horn crimson at the tip, then white, then black. At the base of the horn, embedded in the head, was a ruby, fire, active but entrapped. And the horn was spiral. Even as late as the turn of the eras, Pliny believed that the mares of Bactria were impregnated by the wind.

The pictorial detail of this noble symbol of fire was modified as the knowledge of fire increased. At first he was the gift of the Earth-mother, standing, as in China, where the phœnix represented Fire, the dragon Air, and the disreputable tortoise Water, less for ethereal Fire than for things that burn with active heat. His opposing pole is stagnant water; but stagnant water is less inert than malignant, and so an early legend of the unicorn describes him as standing at the forest-pool at dawn, the other beasts patient behind him, dipping the crimson tip of his horn in the water, and thus removing the cold venom of the serpent and of the spirit of darkness. That is interestingly paralleled in the mythology of Greece, which, however, is more generous to the snake: when the sun-god Apollo slew the Python at Delphi, the gradual effumation of its remains provided the necessary stimulant to the oracle, who hence remained "The Pythoness". In England, unicorn's horn was universally regarded as a specific against poison and the plague until A.D. 1746, when it was at last removed from the *materia medica* of this country, though it continued to be used elsewhere. It was essential to employ the genuine horn. Unicorn's horn was authentic when it produced a "cold boiling" in the water, as did the spirit in the Pool of Bethesda, in the well at Asbama that witnessed the birth of Apollonius, in the divine well of Osiris at Abydos, in the cold cauldrons of Hippocrates or in the Ammonian springs,

and made the water "sweet", as did Moses' rod at Marah. In the sixteenth century, similar miracles were attributed to a complex metallic alloy of Paracelsus, vessels of which broke into a sweat when used for poison. Made from the full tale of the seven metals, it held a maximum of planetary sympathy with man.

§ 7.

The habit of dualism leads naturally to the association of ideas ranged on the same side of the common arena. Sunlight was opposed not only to moonlight but to rain, not only to darkness but to stagnant water. History shows some confusion in the subsequent pairings, but the alliance of the Moon with Water has been consistent and permanent. In each there was that hidden fire that betrayed itself rather by change than by heat. The growing intelligence of primitive man recognised that the rain fed the things he worshipped, the rivers and the trees. It was digested into the potential fire of wood as later thinkers conceived the energy of the firmament digested into the stars. This was a thought that persisted into the eighteenth century, a century that in its early days would have made no quarrel with the statement of Paracelsus that "It is the element of Fire that moistens the Earth with Rain". Mankind must early have discovered, probably by the bitterest of experience, that the rain was very pure as compared with his pools of water wherein was no motion: it came from the heavens. It was a spirit more powerful than his own fire. So, as he offered incense, he also sprinkled Living Water—rain-water, river-water, milk containing incense or water containing salt. The fire that came from heaven, too,

was not like his own fire that flitted in the fens and smouldered deeply in the peats of the dried marshland. Its spiral descent was vivid and terrible. It left no ash. It was of the colour of the sparks that flew upward as if to their primal habitation, of the flame that quitted the sacred wood which burned on the altar. It was of the colour of the golden evenings that hung in the sky, of the golden sands carried down the rivers by the heavenly rain, of the increase of the summer—the seed of Osiris—standing thick in the singing valleys and gently blown and billowed by the widowed Isis. Even before gold was associated with articulate worship, the sacred tree shed its sacred leaves, and these—as thousands of years thence children were yet to learn—were of fairy gold.

Not alone did the Golden Bough call for worship. Throughout the world, dreaming of resurrection, men worshipped at the New Moon. Three or four days after the dwellers on the coast had experienced the worst rages of the tide, low in the West above the sunset and the far-off apple-orchards of the golden Hesperides, hung what Paracelsus in a glorious phrase has called "the Phœnix of the Firmament", the Golden Horn. It was Osiris, come again. It was the horn of the great Ram, the heavenly Boar, the divine Bull; it was the horn of the cosmic Unicorn, worshipped equally with the altar-flame by the Zoroastrian, who explained the spring tides at new moon as its disappearance in the ocean, which was thereby troubled and purified and made Salt. So it was that a race of very different habits of mind, to whom the unicorn was a barbaric myth, originated a conception of speed and purity hardly less beautiful in Artemis or

Diana, archetype of all the Golden Girls whom Shakespeare in a recurrent mood of gloom yet linked with dust and chimneys. On the other hand, the association of the polar pairs Sun and Moon, Fire and Water, Male and Female, led inevitably to the association of Woman with Water as well as with the Moon.

§ 8.

It was thus that the Moon, redolent always of strange lore, became especially beneficent to birth. The earliest symbols of birth seem to have involved the spiral alone. They were the navel, the whorled shell of the snail, and the ear. Thus Minerva sprang from the ear of Jove. Even in modern times, a red spiral is painted upon the door of the bedroom of the expectant Hindu mother, and her amulets include whorled shells : these help the child to perform that spiral movement which immediately precedes the birth. In the universal myths of creation, however, we find always Water. In Egypt, Tem replaced Neter, and Khepera replaced Tem; but whatever name was given to the great original and only One, He made Himself the Waters to dwell in; and there, within an Egg of His own substance, He uttered those thoughts which were creative Words. The Vedas describe the brooding of the Deity upon the Seas, the ancient Indian marriage of Fire and Water. This union is celebrated in a beautiful symbol wherever a Chinese bride and bridegroom prostrate themselves before Heaven and Earth; indeed all ancient races recognised a truth which Paracelsus was to formulate. "The element of Water requires the element of Fire for its operation". Then, the Vedas continue, in a whirlpool an embryo was

produced. As it came forth, it was covered with a golden covering, an expression of what Juvenal put with less felicity in speaking of the newborn child, "red from his mother". Some of the fire or energy of the whirlpool had taken upon itself a fresh, individual existence. Among the Greeks, the idea came beautifully into myth as the birth of Aphrodite. Among the Augustan poets, a favourite epithet for a rapidly eddying stream was "corniger". A similar thought in another aspect informed the sacrifice of curly-haired Mexican children to Tlaloc, God of Water, who was depicted with a spiral wand. Energy was being offered to his eddies. So also, among the Maya, it was the Water-god, Itzamna, chief of the Pantheon, "the Serpent of the East", who was the father of gods and men.

The earnest proselytism of the priests of Ra at On drove moon-worship into a secondary position. The Moon became his left eye only. The Sun was his right eye and his deputy. In Northern climates a change took place which in Africa has never been completed. The Moon actually took upon itself an active malignity. Just as Persephone has darkened into Proserpine, so Diana has become confused with Trivia of the cross-roads, or with Hecate, the erstwhile beneficent goddess of Magic. She is saluted with a curtsey and the turning-over not of gold but of silver. It is the rising of the Sun that is greeted by the hat of the continental peasant and by the bugles of the British Navy. Only the Moon's eclipses have preserved her ancient character. Evil as she may be in some aspects, in a mutilated form we still preserve the story of the restoration of little Red Riding Hood from the wolfish maw of the Night. This confusion

tends to endorse the early tendency to make the Heaven itself the Creator. So, then, in all the gropings of primitive thought, whether of Sun or of Moon or of the entire Sky, conceived as Dyaus or Zeus—"which", says Herodotus, "is the name they give to the whole circuit of the firmament", the connection between Fire, Purity, Deity and Gold is unfailing. Even in the temples of the Maya, a people whose speculations were perhaps not entirely independent of those of our own intellectual ancestors, who prayed to the atlas pillars of the Firmament, the Four Sons of Horus, an object of deep veneration was the Cross of the compass or weather-vane, for this denoted the whole of Heaven. This unfailing connection was renewed afresh with every new creation: it was a planting of fire. It continued individually throughout the manifestations of existence: these were nourished by fire; had not Zeus himself placed the twisted horn of his nurse, the goat of Amaltheia, filled with fruit and flowers among the stars, with whose fertilising radiance henceforth its own was mingled? It concluded afresh with every harvest: for this was a liberation of fire, when the spirit, in what Catullus has called "the eddy of Death", returneth unto God, who gave it.

§ 9.

There was early a sense that only the pure might approach the divine. Technical advances and philosophical speculation did nothing to destroy it, until, at the beginning of our era, a Hebrew audience listened in amazement to the story of the publican in the temple who went to his home justified. The old puritan doctrine required the man to go to the temple justified. The

Assyrian furnacemen employed in glass-making carefully cleansed themselves, not after their duties, but before. Invading generals would sacrifice to the running stream before they crossed it, and that in exactly the same manner as they would placate the gods of a territory whose treaty rights they were about to violate. The feeling was exhibited in its most intense degree when hymns, prayers and libations to the Sea immediately preceded the setting-out of a naval expedition. This superstition has been stereotyped into a "divine law" by most of the current travesties of the philosophy of Jesus, and in the first centuries of our era, theologians extended the principle to embrace the Divine Evil Ones: they prayed not only before they approached the "Mass", but before they crossed the running stream, resort that it was of the deposed Olympians! Indeed this idea, common to Egypt and Assyria, was stamped upon subsequent civilisations almost wholly by the hard dies of Rome and Jewry. At Rome, a time came when only a certain type of fire remained conventionally sacred, but the idea persisted as a barbarous confusion in thought of purity with sexual abstinence. An errant vestal was buried alive, sealed in an underground cell. "The sanctity", says Plutarch, "which for the gods' sake is allowed them, is forfeit when they offend against the gods."

Who can say now whether fire was connected earlier with purity or with purification. Fire and Deity clearly came first of all. When primitive theology became articulate, associations with health, purity and separateness were added to that visible fire that was a manifestation of the god. Zoroaster, whose explicit aim was the purification of human life, taught his followers to worship

Ormuzd in the flame of the altar; it was in a declension from his philosophy that they worshipped the flame. This tendency to an identification of the deity with the holy lamp is seen also in the Hebrew simile of "the consuming fire". Here also, Godhead was associated with a passion for purity, exhibited in ceremonial cleansings and in the preservation of an undying flame in a holy ark. Among many ancient peoples, the appearance of the flame on the altar signified benign approval of the libation, or, more rarely, of the sacrifice. A favourite libation in Egypt was the pouring out of Water. When this was poured at Dawn upon the Earth, there rose in Heaven the radiant deputy of the Lord of Flame Himself.

Divine also were the less welcome effects of fire as punishment. Widespread was the primitive belief, voiced by Heracleitos, in a periodic destruction of the World. In the Papyrus of Ani, the agent of this destruction is Water. All things are to disappear except the Creator, the risen soul, and a "very small invisible serpent", evidently the germ of resurrection and renewal. To Heracleitos, the destruction was to be by Fire. Hence, for example, among the early Greeks—except for some ironical Thucydides—the terror of the ominous eclipse, or earthquake, or eruption, any one of which would cancel a concluded plan. Fire was worshipped then in dread; and if this was true of the triumphant years of Greek civilisation, how much more of the savage villager. It was for him an inescapable conclusion that the evocation of fire was due less to the methods of concussion or friction—unless, it may be, where a boring motion was employed—than by the religious incantations with which

they were usually accompanied. The village firemaker was its wise man or priest.

§ 10.

Thus it was that legends of gods and heroes continually involved fire and gold. We need not go beyond those races whose habitual thoughts are the foundation of later European philosophies. The goose that laid the golden eggs was originally—in the Sanskrit Panchatantra—a serpent. In Egypt, Hathor was called also Nubt, "the Golden One"; the blood of Ra, the noon-sun, was of gold; Khensu escaped from Bekhten as a hawk of gold, and in this guise also the later Egyptians conceived that the souls of the just fled to Heaven to merge their identity in God. To the Chinese, gold was "the heavenly essence". In India, it was the divine "life-giver" and "a form of the gods", the Atharva Veda referring to gold as "fire, light and life immortal". The deity of the Hebrews was manifested in fire and cloud, but Job is also told that the Almighty shall be his gold. It was with an axe of gold that the Druids cut the sacred mistletoe and sacrificed their pairs of white bulls, and the fire-sacrifice of Beltane has by some writers been identified with the worship of Moloch, each exhibiting the common custom of purification by leaping through the fire. The gods of the Scandian sagas lived in a realm of fire, Brünnhilde being thus protected from a bridal awakening of any but a hero; in fire they lived and moved and had their being; it was their element and their vehicle, and when the carpenter had mended the wheels of Mother Hulda's chariot, the chips thrown to him were of gold. There are Finnish poems that describe Fire as

a Child of the Sun which has come down to us from Heaven; there it was "rocked in a tub of yellow metal in a large pail of gold". And here we cannot forbear the remark that the South American god of rain is called Itzmatul—"that which holds the substance of heaven", for Pindar reminds us that Jove himself loved Danaë in the form of a golden rain, "self-flowing gold". Wallis Budge says that the belief that every King of Egypt was the offspring of a similar union persisted throughout Egypt for about three thousand years. The French have seen this "Pluie d'or" in the blossoms of laburnum. In Homer, fire was produced from the friction between Zeus and Hera, Hephæstus, the fire-kindler, being picked up by the heel amid the general rough weather and thrown down by Zeus to the Earth. The cloud in which Venus rescued Paris from Menelaus, or Butes from the Sirens, was of gold. Hesiod follows tradition in envisaging lightning as a punishment of Zeus, but conceives that a subtler punishment followed: for Zeus, having given "the strength of untiring fire to wretched mortal men who dwelled upon the Earth", became offended to such an extent as to withdraw the boon; whereupon Prometheus, already the offender, "cheating Zeus, stole back for mankind the far-seen splendour of untiring fire in a hollow fennel-stalk", having lighted a torch at the chariot of the sun. Zeus replied by cursing the Earth with Pandora, fashioned, appropriately by Hephæstus, to bring evil, so that an inevitable misuse of the golden gift was to bring Man at last to the gloomy age of iron.

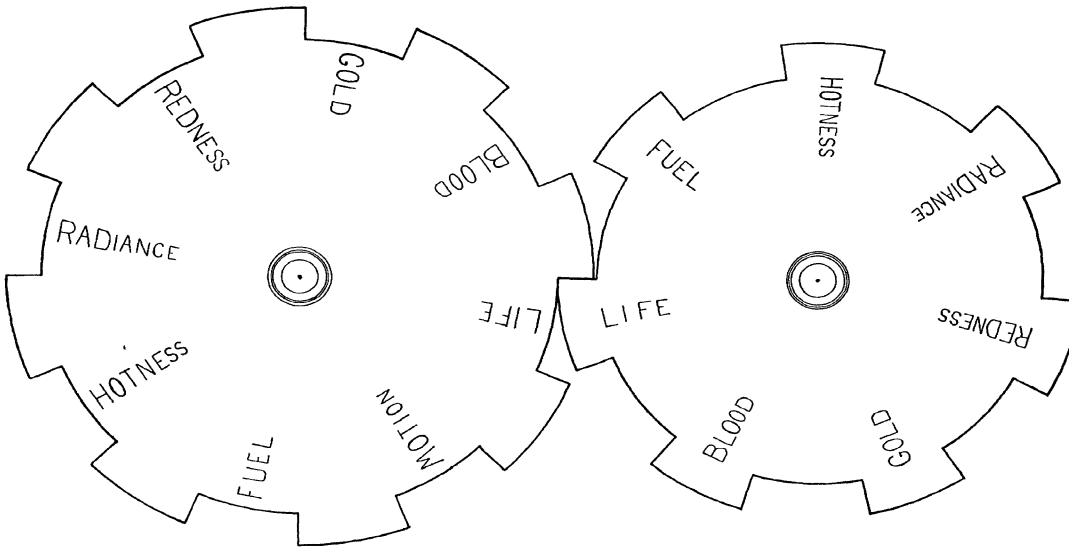
Pindar recalls that the mother of Apollo or Phœbus, here as in Homer the pure god who cannot lie, who shields mortals from disease or stabs them with fevers,

prince of archers, the genial father of the sharp rays of light and of almighty fire, is herself "the golden one", gold being further allied with "the upright mind". There is a clear connection with the custom, followed by the Gauls, of throwing sacrificial gifts of metallic gold into the sacred lakes. Indeed these ideas may be paralleled, with various degrees of nobility in conception, from most tribal mythologies. Recent investigations have shown that to the Aztecs gold was an excretion of the gods; to the Maya, the symbol of deity was the serpent with golden feathers—a symbol we find in Lucilius, just as much African as American—the old spiral symbol of fire. Theology-makers have played long and unhumorously with the grave problems of what the gods ate and breathed. What was the Nectar? What was Angel's Food? Fire? Aurum Potabile? And what were these? "Father" Louis Coulange says that "a theologian worthy of the name is competent to find his way out of any impasse". So Justin explains that having no teeth, angels absorb their food as fire devours combustibles. Tertullian, however, opines that their food is made of an aery material. Honoré of Autun says "The Angels have ethereal bodies, demons aereal bodies, men terrestrial bodies. The bodies of angels are simple, that is to say, made of pure æther. Æther is fire, that is to say, the fourth element". Honoré de Balzac has explained why angels are unable to obey the command to be seated.

§ 11.

Referring to our first "Mnemonic", if we mentally allow the wheels to turn we shall find that such a series of identities as deity, fire, life, blood, wood and gold

THE PROTEAN METAMORPHOSES



as anciently conceived.

[To face page 18]

provides material for essays on some fifteen simple equations and the history of fifteen psychologically (and genealogically) related concepts. So in Egypt we find the Divine Right of royalty crowning the brows of the Pharaohs with the uræus; and serpents, worms and scorpions—all both good and evil—in the dramatis personæ of their religion. In Mexico the association with deity was equally direct, the root *-coatl* actually appearing in many of the names of the gods. Quetzalcoatl, the good god of fire, rain, wind and life, was borne on a raft of entwined serpents. This god, it may be observed, had one of the properties of the phœnix, and upon his fiery dissolution his heart shot up to the heavens as Citlalpol, the planet which we in Europe have called Venus. He was light-coloured—the *white* motive—and the arrival of Cortes with his priestly blackguards was at first hailed by Montezuma as the return of Quetzalcoatl. The word *coatl* itself referred to the feathered stick of stone that was commonly carried on journeys as a talisman and received thank-offerings of blood on their successful conclusions. This is almost exactly the snake-headed boomerang which was the magic wand of the Egyptian Horus. The Algonquin had a goddess, and so had the Aztec ("Coatlicue"), who was at one and the same time half woman and half serpent. So we have the serpent as God, the serpent (in Chaldean lore) as the opponent of God, the serpent as fire, the serpent as water, the serpent and the stick, the serpent and Helicon: there is no end. And the feeling persists; to take an example at random, in *The Girl and the Beetle*, Barry Pain has this:

> "Just then, out of the grey darkness came a thread of light, like a little snake, moving very quickly and curling about

> as if it were glad; it hurried towards the great River of Light, and melted into it, and was gone. . . . It was a soul going home."

Or, if we examine for a moment the holiness of wood, we recall at once that in a highly civilised community the garland of the sacred olive was, by token, a crown of gold. This was because its oil was latent fire. Keats was to write with truth "the trees that whisper round a temple become soon Dear as the temple's self", but at that time it was the other way about: the temple was placed there because the wood was sacred. The puritan Isaiah complains that the ash, planted by its husbandman and nourished by the rain, is cut down and used for baking, for roasting, for domestic amenities and also for worship: of part, with the chuckling delight of the young child in physical comfort, he says "Aha, I am warm. I have seen the fire"; to part he prays "Deliver me, for thou art my god". He was probably offering the customary apology to the spirit of the tree for felling it, for the wood was the temple, not the object of worship it has always seemed to Puritans; but indeed, as life became more complex, it was quite competent for one morsel of wood to say to another "I am holier than thou". And if it were possible as between morsels of wood from the same source, how much more as between tree and tree. In quite recent times, men have believed that the golden gifts of the fire-spirits, or fairies, turned into oak-leaves. The Highlanders, in "Beltane", used, not flame, but branches of the rowan or rune-tree. Wood was fire, just as gold and blood were fire, and just as the long-lived phœnix was burned in her blood, so was wood consumed with that which it was nourished by.

Tree-worshippers would not have understood a wrangle among morris-dancers as to whether Sellenger's Round should be danced round a fire or round a tree; such a contention is based precariously upon a point that has position but no magnitude.

As to Blood, Life and Fire, they form an ancient association that is illustrated by every tale of lamias and vampires. There is much of the apparatus of vampirism in Homer's story of the visit to the underworld. The hero poured a libation, but without active fire, of milk, honey, wine, water and meal into a square trench he had digged. Then he killed the sacrificial victims, allowing their blood to stream into the pit. Immediately a multitude of ghosts swarmed with shrieks about him, making pitiful and desperate efforts to obtain a draught of that red fluid which would give them a brief travesty of life. Somewhat incongruously, as it may appear, Odysseus kept them at bay with a drawn sword, but possibly because it was of iron or steel, not because it was edged; though it must be admitted that in the Egyptian otherworld, evil souls were thus decapitated. His mother, sitting silent by the trench, did not know him until she had drunk the blood. This scene is not repeated in Virgil or in Dante, but that cannot be because they wished to repudiate the special character of what is still regarded as at least the special vehicle of Life. Three hundred years after Dante, Shakespeare builds a pun on the ancient identity, putting it into the mouth of Lady Macbeth, who said that she would "gild" the faces of the grooms with blood that it might seem their "guilt". Shakespeare's contemporaries needed no gloss on the relation of blood and fire to gold.

§ 12.

The fire of active combustion was susceptible to the same classifications and categories as the latent fire of fuel. Fire from wood, earth-born but rain-nourished, was to be regarded as more sacred than fire from flint and steel. So it was used always for the "need-fire", to which we shall return. It was employed for the re-ignition of the sacred communal fire at Rome when in some national vicissitude that had been neglected, and it is still necessary in the Brahmin sacrifices. Fire from heaven-born sunlight was usually, however, the holiest of all. One factor contributory to this feeling was the diversity in the luminance of flame, and flames were not in any emphatic manner differentiated from minds, for the idea of mind was derived from the observation of flame. So Frazer tells us that the Chinese, kneeling in front of a candle, will 'take the oath' in this manner: "I tell the truth and the whole truth. If not, as this candle is blown out" (and here he will blow it out) "may my soul be blown out". Minds and flames alike had their home and origin in the heavens, and thither, especially among peoples that employed cremation, they tended to retreat when freed. As late as classical times, the body of a child that had died too young to have functioned as an individual was not cremated; it was not entitled to that respect. Cremation was, however, no passport to the heavens. It was merely a clearance from the port of issue. As Heracleitos put it, the soul of a just man was a dry light, leaving the body with the speed of lightning to be immediately received into the rarer fluid of heaven, whereas the soul of the wicked was a damp, heavy, smoky flame slow to kindle, sluggish in ascent. An

illustration of the universality of this Egyptioid conception may be taken from Paracelsus, two thousand years later. Writing of the climax of all separations, as he regards the Christian judgement-day, he says that "the cursed shall be thrown down like stones and lead, but the blessed shall rise in the air like eagles". But the poles of good and evil in the human soul might also be referred to temperature and direction as well as to speed. Heracleitos, like Elijah and like the Maori, had evidently envisaged a rapid journey to the sky in a whirlwind of fire, but devils and witches arrived on the earth always with a *cold* whirlwind, and people who believed that would also tend to believe that their whirlwinds circled "widdershins".

The distinction drawn by Socrates, particularly as between earthy fire and solar radiance, is so valuable that it has had many echoes in later writers. Apuleius tells his host, Milo, in defence of Pamphiles, she, like Virgil in the Georgics, having divined from the flame of the supper-candle that rain would come next day: "Although this light is but small and made by the hands of men, yet hath it a remembrance of that great heavenly light, as of its parent, and doth shew unto us what will happen in the skies above". Francis Bacon writes: "Note also that the flame of the candle is troubled; and doth not only open and move upward, but moveth waving to and fro; as if flame of its own nature, if it were not quenched, would roll and turn, as well as move upwards. By all which it should seem that the celestial bodies, most of them, are true fires or flames, as the Stoics held; more fine, perhaps, and more rarefied than our flame is. For they are all globular and determinate; they have rotation;

and they have the colour and splendour of flame: so that flame above is durable and consistent, and in its natural place; but with us it is a stranger, and momentany and impure; like Vulcan that halted with his fall".

§ 13.

It is now proposed to advance yet one more explanation of the genesis of alchemy. Novel though it may be, there are facts and allusions in the later works of its initiates, those of the sixteenth and seventeenth centuries, which any other explanation seems to stultify. It is based on the repeated identification of gold with fire and with the sun. Let us premise that they certainly had special knowledge, that they protected this knowledge by a system of synonyms, and that nevertheless morsel by morsel some of this knowledge was betrayed by plausible charlatans to criminals. Let us take two illustrations of this knowledge, to wit, phosphorus and the fire-making powders later termed "Pyrophorus". It is said that phosphorus was "discovered" by Brand at Berlin in 1669 and that Krafft bought the secret. Here, in Paracelsus, who died in 1541, is the entire recipe:

> "Take urine and thoroughly distil it. Water, air and earth will ascend together, but the fire remains at the bottom. Afterwards mix all together and distil again four times after this manner; and at the fourth distillation the water will ascend first, then the air and the fire, but the earth remains at the bottom. Then receive the air and the fire in a separate vessel, which put in a cold place, and there will be congealed certain icicles, which are the element of fire. This congelation will take place during distillation, but the solidification is much more ready when cold".

Criminals who purchased this secret from the baser alchemists seem to have carried the phosphorus in stalks or in straw as Prometheus did. The following quotation is from the *Demonolatry* of Nicholas Rémy, a contemporary witch-torturer, who was a voluminous reader, a lucid writer, an officer greatly respected, and, at such times as he was free from his obsessions, a man even honourable :

> "The following story is the very brother to that of Medea, who sent as a gift to Creusa the daughter of Creon magic fire enclosed in a box, by which the palace in which she was then was burned. Joanna Schwartz at Laach, in March of 1588, tried with all her might to get Françoise Huyna to give her a piece of dough before she put it in the oven so that she might make a cake with it for her children. But Huyna refused her, saying that the dough had been measured out to last the whole family for a certain number of days, and she could not give any of it away without causing her own house to go short. Thereupon Joanna never stopped pondering how she might fittingly pay her back for that refusal. But she had not to wait long; for her Demon gave her a napkin in which were some tiny morsels like chaff, and told her to secrete it in Huyna's house, and to do so quickly; for soon after she had done so, it would happen that the house would suddenly burst into flames and be consumed with all its furniture. Accordingly she rolled the napkin into a ball, went to Huyna as she was busy in her bakehouse, and offered to sell it to her for use in her loom, which she had heard she was getting ready. And when Huyna said that she did not need it, since she expected to have more than enough to do in household duties, nevertheless the woman put it down in a flour-tub that stood near by, saying that if she had no use for it then, she might like to use it later. Hardly had she left the house when the bin containing the napkin burst into flames, and the whole house caught fire

> so rapidly that no help could be brought quickly enough. These two women separately gave the same account of this event".

To us, of course, it is entirely credible. If it could not happen nowadays, that is because we do not employ wooden bakehouses with roofs of thatch.

Rémy also refers to powders that might be used for the exceptionally quick production of flame. The formal history of chemistry teaches that these pyrophoroi were "discovered" by Homberg, a scientist of some renown who died in 1715 at the age of 73. Now Homberg was definitely an alchemist, and Rémy's account of the use of these powders by incendiaries was published in 1595. He writes : and the italics are ours :

> "We need not be greatly astonished at this power of the Demons to cause such rapid and instantaneous fires, for even to this day *we have men who are most skilled in doing the like. I do not refer to explosive powders and such inflammatory substances,* by the use of which we see whole houses quickly set on fire and destroyed; *for they are matters of common and everyday use.* I refer to some obscure method which is beyond normal human understanding . . .
>
> I know from Pliny that naphtha has such an affinity for fire that it very readily conducts flame; but he is wide of the mark when he says that it actually causes fire. For, from what I hear, it can be kept with perfect safety for many days in the same room with a bright and continual fire burning".

It can hardly be doubted then that the alchemists had also secrets which they kept, secrets of little immediate commercial value, secrets that could not be exploited save by the initiate. Men of probity, unless they were professed candidates for introduction to the occult and

arcane, never heard of them. The serious alchemist was bound in good faith to his colleagues to mislead any unworthy or unproved enquirer. He misled them, therefore, and behind their backs he laughed at them. Only a blockhead, said Paracelsus, would think that the word "sulphur" denoted the native mineral or that "mercury" signified quicksilver; these were synonyms of Fire and Water. He has hard words for medical fops and dudes. Initiates of Alchemy, he said, must walk about as black as charcoal-burners. He candidly admonished them that to be a good alchemist one must not be disgusted by the daily smoke nor discouraged by the coals. "Fire alone is the whole work and the entire art". "Fire containeth in itself the whole of Alchemy". And Fire was Gold.

§ 14.

Fire was Gold. And it is contended in the Seventh Chapter of the present volume that the prime secret of the alchemists was oxygen. Here we can do no more than advance a few superficial facts that may make such a statement a little less incredible.

From the wood-fire to the oxy-acetylene blowpipe and Moissan's electric furnace, the goal of the chemist, the glass-worker, the inventor of glazes and enamels, the smith and the metallurgist has been high temperature. Special provision against this source of difficulty is recorded in the cuneiform inscriptions; the Assyrians—who worked in glass, glazes and enamels—having mastered it by the treatment of their wood and the careful aeration of their furnaces. The fuel consisted of the resin-bearing styrax, cut in Ab, the hottest month, and preserved from weather in leathern cases. An efficient

draught passed through the furnace and out at the top, through vents, called "the eyes". Lest the recipe should be lost by any misunderstanding, the injunction is repeated and reiterated—though each stroke of each letter had to be cut in stone—"Keep a good, smokeless fire burning".

One thinks of Palissy, father of French ceramics, from whose age the Assyrian hieroglyphs still protected their secrets, of Palissy, burning not only his furniture but the very floor, watching his furnaces by day and by night lest the temperature should fall, trembling in tragic failure and finally triumphing with a margin of a few degrees. The recovery of the lost art was at stake, and, for the man himself, fame or ruin. He was neither alchemist nor antiquary, but he would have seen the connection between high temperature and gold; and he found it soon enough to enable Shakespeare to be topical about the serpent's "enamelled skin". Paracelsus refers to such researches where he writes "The ancient artists marvellously wearied themselves at conjoining tinctures" (that is, slags) "with fire, for they anticipated a medicine in their almost sacred conjunction, but all in vain". It was a matter of fusing metallic oxides on to refractory surfaces. Such oxides were, of course, the calx or ash of the ore or metal, and a common name for them was "glass" in the sense of a glazing, for "glass" was originally the very fine ash from resins, principally potash. Now Boyle says "Raymond Lully expressly reckons it among three or four of the principal virtues he ascribes to the philosopher's stone that it makes glass malleable". The ancient alchemist Morien made a similar statement, and in the *Book of Alze*, still extant, is the double statement: "It makes glass malleable, and turns crystals into

gems". The alchemists would certainly use nitre as the source of the oxygen, for we know that they used fusion-fires which were a mixture of sulphur and nitre; and Paracelsus says "By means of this salt, are brought about many of the arcana of Alchemy".

Let it be clear that we have been discussing not the alchemist's hope, but an alchemist's secret. Neither in their system nor in our own does the transmutation of metals involve any inherent impossibility. They certainly attempted it. They certainly failed.

§ 15.

The story of Bahram the Magus seems to have been written by someone with an undigested knowledge of alchemical methods, vitiated by the supposition, of much later growth, that metallic gold could be produced by the "projection" of a certain powder. In spite of this, however, the ancient identities stand out in bold relief. First, let us note two points which illustrate the muddle-headedness that could hold two later beliefs with a complete innocence of their mutual destructiveness: that explains so much in human history. Though the gold-making superstition is completely accepted, the mother of Hassan is made to remark with a naïve irony: "These people are great deceivers, who know the art of Alchemy, and trick people and take their wealth and devour it by false pretences"; and, in the tale, the alchemist actually did make gold from copper and from brass and yet did actually gut his host's dwelling of everything of value. Yet, though with all the theatrical "business" of an Elizabethan charlatan, he throws a yellow powder into the crucible, hot on the bellows-blown charcoal-fire, he

echoes in his conversation and in his acts the authentic ideas of alchemy—or, if that is going a little too quickly—ideas that had nothing at all to do with making metallic gold. He was a Persian and a Magian, swearing not "by bread and salt" as did the other characters, bread and salt being life and fire by a further remove, but "by Fire and the light and the shade and the heat"—which he worshipped. The blood motive enters: "he used every year to take a Moslem and slaughter him over a hidden treasure". Hassan is made to ascend into the Empyrean, above the cloud-level, the no-man's land—our "stratosphere"—between the Lower Air and the Region of Fire—the playground of Icarus and Dædalus—or, in some cosmogonies, the Region of Fire itself. This was always the golden region. Virgil tells us that the gryphons dwelt there. According to a traveller's tale much doubted by Herodotus, these winged things brought it to Earth in Arctic Europe, and the one-eyed Arimaspi stole it from them, picking it, one imagines, from their beards as the Arabs plucked the resin, ladanum, from goats which had browsed on the scented bushes. It was the region also of eagles, the birds of Deity. From this region, then, Hassan was bidden to bring to Bahram bundles of a certain wood that grew in that place alone. "This wood", said Bahram, "is the material with which we shall perform the alchemical operation".

And Paracelsus writes: "What materials and instruments are required in Alchemy? There is need of nothing else but a foundry, bellows, tongs, hammers, cauldrons, jars and cupels made of beechen ashes".

§ 16.

Mythology did not usually content itself with the recognition of the principle—evidently masculine and divine—of motion, of life and of change; it sought also to explain the origin of the passive or not yet animate or virginally feminine materials upon which this spirit brooded. Variously it saw the primal matter in Earth, in Water, in Air, and in the thinner and more tenuous outer chaos, which it called indifferently Heaven and Ether and Fire. Early philosophical speculation followed the same lines. Thales was the protagonist for Water. Anaximander supposed that this primal matter was the infinite reservoir actually external to the Universe, a region of which we hear little in ancient thought, except indeed that that clean feeder, the vulture, strayed thence to our own deplorable strands. Anaximenes recognised it in Air. The followers of Pythagoras worshipped it in Number. Heracleitos of Ephesus found it in Fire. The Universe, in his system, came not from Fire and Water, but from Fire alone. This again is Egyptian. The four elements, the four Rams' Heads of a common body, had one common origin in a Being that was Purposive Energy.

The conclusions of Heracleitos largely moulded the physiography of the Stoics, and they are remarkably in line with the ideas of the medieval alchemists and with current thought of our own day: the unceasing mutation of matter, the cycles of evolution from fiery chaos to fiery dissolution (the Stoic resorption into the Creator), the identity of Energy in its various manifestations, the procession and retrogression of physical states, gas, liquid and solid, which, like his contemporaries, he named Air, Water and Earth, just as his name for Energy was Fire.

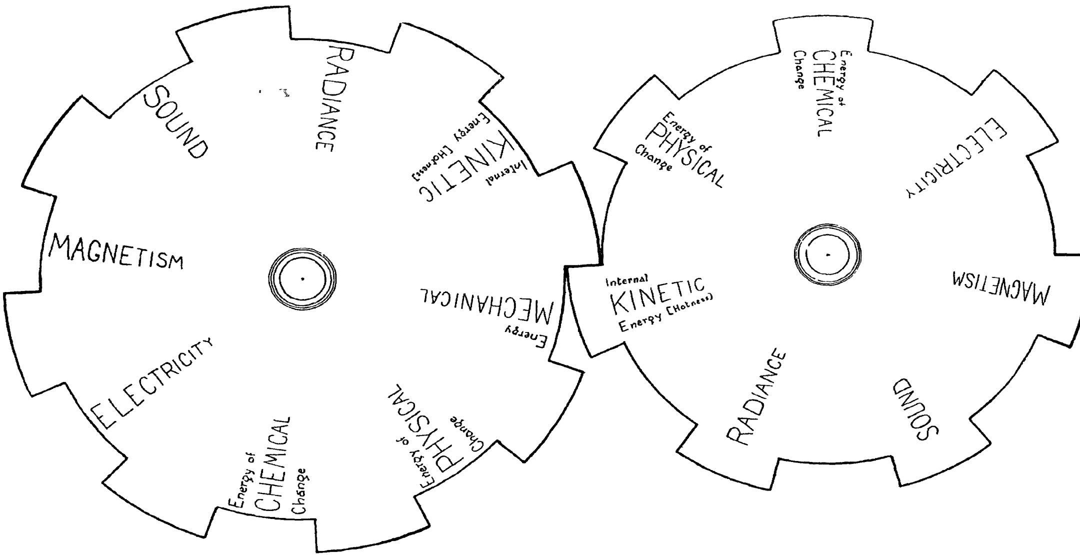
It was indeed that cosmic fire that enveloped the terrestrial atmosphere, but it was also the unchanging principle of mutability. "As gold is given for everything, and everything for gold, Fire", said Heracleitos, "is the general medium of exchange".

It is easy now to demonstrate this truth with multitudinous illustrations from the laboratory and the devices which issue thence. So coal is paid for steam-power to the boiler, power to the dynamo for electricity, electricity to the filament for light and heat, or to the solenoid for magnetism. Francis Bacon writes of Fire, in recommending the distillation of wood under pressure, "This Proteus of matter, being held by the sleeves, will turn and change into many metamorphoses". For Heracleitos, the data were limited; yet he knew that fuel was exchanged for heat, and that when steam and water lost heat they became water and ice.

§ 17.

If Heracleitos' concept of the primal matter had been translated as Energy, and not as Fire, the history of Fire might perhaps have escaped a long confusion in thought which it is our hope to unravel. Fire itself may fulfil most of the attributes for which we should look in a Principle of Mobility; but Phœbus needs a vehicle, a vehicle, be it granted, that only he can drive. Those philosophers were expressing a great truth—though their conclusion might not cover every possibility—who said that the Womb and the Chariot of Fire was Water. Here, however, are some of the connotations which at different times, and in different connections, have attached themselves to the word Fire:

THE PROTEAN METAMORPHOSES



as conceived in the declining Nineteenth Century.

[To face page 32]

1. The principle of mobility, energising the Universe; Energy, reserved or in operation. And this we have discussed.
2. Fire as fuel in active combustion; and this is the burden of the second chapter, in its history of fire-making.
3. The third chapter discusses Fire as the Primal Matter.
4. Chapter Four sees Fire as the Preservative Principle or Balsam, the Soul of things, the Flame contained.
5. A special instance of this is discussed in Chapter Five where Fire appears as a Principle common to all Fuels.
6. Terrestrial Fire, being associated with Earth, might be corrosively hot or bitterly cold, having potentialities of maleficence and destruction. The developments of this idea in theories of temperature appear in Chapter Six.
7. Chapter Seven exhibits the atmosphere as an arena where the benevolent manifestations of Fire struggled with the malign, all these ghosts suffering an impartial exorcism at the hands of Boyle's Law.
8. Celestial Fire as a radiant, beneficent, fertilising influence, essentially temperate, sweetening the Air and the Earth, develops in Chapter Eight into "igneous particles", a "pabulum vitæ" that we now call Oxygen.
9. Chapter Nine is a perspective of the development of public and private lighting and heating, but we see Fire in its rôle of

10. The Flame Issuing more analytically examined in Chapter Ten.
11. In the Final Chapter, Fire is seen harnessed.

That is suggestive of an idea already canvassed. Old science provides a vocabulary for modern poetry. The omnibus use of the word Fire has perpetuated conceptions and significances which in our speech and in our general literature are imperishable. Here we return to that noble image of a celestial reservoir of vital energy, the lonely Unicorn, lonely because peerless, robed at last in the five glorious colours of perfection, swathed in the rainbow, presiding between Earth and Heaven over the tides, the streams, the winds and all the flowings of the World; the Golden Hind, symbol of energy and purity, immanent in all motion. "In all things", wrote Virgil, "there is Jove". To an age of energy and filth, his is the rebuke of primitive times, surviving history, even that ignoble period of history whose professed celibates made Diana a witch and saw the Unicorn through lecherous eyes as goat and devil. We can be deaf to his rebuke no longer. We are beginning to see that Man has been the Man with the Muckrake, unready rather than disobedient to the Heavenly Vision.

§ 18.

In the long confusion of thought of which we have spoken, the Unicorn has indeed stood also for active fire. To some of the soi-disant "Christian" pseudo-Peripatetics of the Dark Age he became an allegory of baptism. His fire was subdued by the dewy coolness of maidenhood. Only a virgin, as representing Aristotle's Qualities of Cold and Moist, might allay his fierceness and destroy his

strength. But here the medieval allegorists overshot the mark, though the history of steam-power—a manifestation of Terrestrial Fire—might seem to justify them as true prophets: the final act of his subjugation was to transport him to the palace of the King. A less trite and more fitting end is assigned him by John Guillim in his book on Heraldry: "The greatness of his mind is such that he chooseth to die than to be taken alive. . . . Rather than be compelled to base bondage, he will lose his life". A picturesque and unconscious description of energy transformations! For Man has learned to subdue him—that is, he has learned to *store* energy—and now need only master his own inertia and selfishness to make the hidden strength of the Unicorn the manifested Glory of the World in a new and cleanly Age of Gold. The Age of Soot has constituted an apprenticeship. In yielding the dynamo and the accumulator, it has provided the harness and fashioned the bit. But it has served its purpose. It is an age that Man must close. It is an Age to which he must nevermore return. He may go back now with his dynamo and his accumulator to those earlier gifts, the windmill and the water-wheel, the wings and heels of Pegasus.

CHAPTER II.

THE GOOD COMPANION.

When the lamp has guttered on the sill and all its smoke has issued, then come the black goblins.

—*Persius* (*Satire V*).

Bring a light and draw the curtains.—*Lucilius* (xxix. 42).

Pile up the dry wood while you may.—*Horace* (Odes III, 17).

§ 19.

Polybius felt that the first necessities of life were cattle and slaves. Yet we may read in his pages how invading armies opened the sluices and filled up the wells, how pitch and resin and tow were prized as tribute or as presents—and need we labour with his shade the significance of salt? The necessity of fire and salt is familiar in all the histories except perhaps in Sallust who appears to believe that the inhabitants of Africa did not use salt. Three centuries before Polybius, however, Herodotus tells us that salt, like frankincense, was part of the tribute paid by the Arabs to Persia. Writing at about the same period, Thucydides describes how the Athenians at Delium had been driven to use the sacred water, how they in turn harassed the men of Syracuse by "destroying their pipes of drinking water carried underground into the city", or, since we quote him, how, when the Athenians were besieged at Plemmyrium, "the water was scarce and had to be fetched from a considerable distance, and the soldiers could not go out for firewood without being cut off by the Syracusan cavalry"

or even how Megabazus foiled his naval opponents at Prosopitis by draining the strait between the island and the mainland, leaving their ships high and dry upon the sand, impotent as fish out of water.

Water and Salt are found ready for use by all the animals; we inhale both of them from the Air on every breath even when we are not employing them consciously; and it has often been remarked that the first essential sign of humanity was the making—we should rather say the preservation—of Fire. In this instance, it will be well understood, we are speaking of Fire as the hot red helper of the hearth, fuel in active combustion.

§ 20.

In this form he is such an old friend. We have always known him. We have never let him go without regret. His passing is the image of all the mortalities that ever were. Evening, Autumn, Dissolution, the Dying Fire, these are linked in a melancholy association of insecurity often far deeper than conscious thought. Pessimism, scorning one analogy and blindly accepting another, is always ready moreover to remember "The rose that once has bloomed for ever dies". Yet Spring and Morning are busy with buds, since for both there is a new return of Fire. In the first days, however, they did not dare to face its disappearance: it was the one live thing that abode with them: the fire was preserved. It arose, fresh and glowing each new day from the sloughed ashes of the night, deepening its association with the serpent, generating inevitably—since the bird figures in most primitive fire-myths—the conception of the Flying Red Thing. There was a red dye attributed to the

Phœnicians. Its name among the Greeks was Phœnix. The word has become imperishable as a description of the immortal bird of fire. In its general attributes, though certainly not in appearance, it is derivative from the green stork-like Benu bird of the Egyptian Otherworld.

There was real anxiety, except, perhaps, among the immediate wardens of the fire, about its preservation. Once, fire had been lost; it must never be lost again. So, almost universally from Scandinavia to Africa, arose the worship of a sacred inheritance, each tribe tending its fire in a tribal prytaneum, an instinct that became the foundation of the philosophy of our own era. It seems impossible now to decide whether Plutarch was misled by an echo of the ancient identities when he wrote that the treasure in the Scyth prytaneum was metallic gold; or whether he was right, and the Scyths really venerated this pale symbol of Fire as their modern descendants worship the ikon. Yet their god was Vesta and their oath "by the Royal Hearth". This people has long fascinated its neighbours. Thucydides might have written at any time in the nineteenth or twentieth centuries as he actually wrote twenty-four centuries before:

> "In numbers and in military resources, no people in Europe can bear comparison with the Scythians, for there is not, even in Asia, any nation that would singly be a match for them if they were in accord among themselves; though, of course, they are inferior to other races in general intelligence and the arts of civilised life."

Ovid would have endorsed the latter sentiment; doomed to a lifelong exile at Tomi, he is only not unprintable about them because unprintability in another connection had been the cause of his banishment. Virgil pictures

these early Russians as enjoying an extremely restful existence in deep caves where they lay extended by the side of monstrous underground fires, and Herodotus, in whose pages the sacred gold is described as taking fire, leaves his reader with the impression that this gold may, at least originally, have been amber or frankincense, or indeed any other resin.

§ 21.

In the times of history and a little before them, the preservation of fire continued informally even when it was not associated with religion. Its expiration meant bothering the neighbours, or, a last resource not always possible, an actual re-kindling. The essential secret of its preservation was so simple, once it was known, that failure was almost a disgrace. It consisted in this: to retain the ash. This was itself the vehicle of an early sacrament, persistent in Australia and in Africa, where it is rubbed into gashes made at first, we may surmise, in ecstasies of religious devotion. Early Man, always anthropomorphic, identified it with the subtle solute of his own blood and tears and sweat. It was the terrestrial necessity which had combined with the divine necessities of water and fire to form the human organism. The salt-cakes of the classics typified the cold ash in its aspect of funereal desolation, fire-deserted.

Thus the "ash" or "salt" or "glass" has long been associated not only with the sackcloth and mourning of the Hebrew or with the funeral ceremony of the Mediterranean civilisations; it has also stood for the undying fire. Hence its universal history of respect and reverence. In many races it has stood for hospitality, its

presence on the table constituting a consecration, and its container—or cellar, as we call it as if speaking of wine—has passed down the pedigree as a sacred inheritance and heirloom. "He lives happily on little", says Horace, "who possesses the delightful sight of the old-fashioned family salt-cellar on his modest table; neither worry nor greed robs such a man of nightly sleep". As the undying fire, salt appealed to the alchemist. It was in the same Egyptian rôle that, having first been solemnly exorcised, it became the chief ingredient of the ceremonial brine, or "Holy Water", of the Roman Church, and of their mimics, the witches. Paracelsus thought that a sprinkling of salt would resuscitate drowned flies; certainly, thrown over the shoulder, it acted like vitriol upon a pushful demon. Thus it has been written by credulous priests that the devil-possessed were *burned* by it, the formula for the Roman exorcism recalling that thus "the prophet Eliseus" cured water of its barrenness. It is taught also that wheresoever this solution of salt shall be sprinkled, all infestation of the unclean spirit will depart and all fear of the venomous serpent will be chased away. The same religious corporation "exorcises" a child before baptism by placing salt in its mouth. There are very early symptoms in history of this feeling for the undying fire. They are naturally connected with its preservative properties; it appears from Herodotus—and hardly doubtfully—that persons might in his day be embalmed in salt.

The light and fluffy residue from burned wood is most admirably adapted to its twofold rôle; it interposes a screen which prevents undue loss of heat from the fire by radiation into the atmosphere—and it permits just

such a rate of change of air as will enable the smouldering combustion in the charred embers to continue. There are many experts on the wood-fire among modern English country-folk, and they will tell you that the ash must be kept upon the hearth. A visitor is shown fires that have never been allowed to go cold within the memories of several generations. A little wind will always stir them to a glow. The philistine will throw cut logs into a grate or basket intended for pit-coal, but a sensitive mind experiences discomfort in the absence of the appropriate ritual care. Whether the logs, each three feet long, are laid horizontally on dogs on a raised hearth with a picturesque iron back, or whether they are piled on end, musket-wise, they must lie close together, "kissing".

§ 22.

As to the source of these logs, the experts are unanimous: for general use, the wood of the ash tree is without a rival. We might have expected it. The homonym is no accident. The tree is ash, too, but it is ash-wood.

Burn Ashwood green,
't is fit for a queen.

It will burn alive or dead, wet or dry, old or new; and for this and other reasons, the ash in our own country holds a special place in woodlore. The three Norns dwelled by a springing water under the branches of such a tree. Its top was in the sky, the perch of a watching eagle. Up and down its trunk, a squirrel played Mercury. In its roots were the mansions of Hela who entertained the departed spirits of men. It was called Yggdrasil. Man was made from this tree, and his vicissitudes were

reflected or premonished from its buddings and dis-leafings. Its properties were not only to be fuel, but also to supply medicinal juices, and an influence antagonistic to all cold, whether this cold were disease, death, evil, or merely low temperature. A spoonful of ash-sap is often still the first food of a new-born Highland baby. Even further south, Pliny proved to his own satisfaction that a snake would rather crawl into a flame than cross a circle of ash-leaves. So too its oil was used here against deafness and toothache and snake-bite, and the barks and juices of many other trees acquired similar significances. The oil from the walnut-tree was a specific against rabies. An infusion of tamarisk leaves would cure jaundice, colic, spider-bites and the bites of all snakes except the asp; "it is sovereign", says Evelyn, "against the spleen".

The parenthood of the tree is deepseated in early human wondering. Prospero took Ariel from a pine and threatened to enclose him in an oak; and the idea has been held to have originated in Brazil, where the Yurucares said that the creation of men was performed by a similar release effected by the god. It was still, of course, a creation from Fire and Water. Among the Britons and Romans, the parent-tree was the Oak—did not men formerly feed upon its egg-like fruits?—and this tree, especially in a naval context, has been still more successful as an English totem. The Britons worshipped it also as the God of Thunder, and it provided the fuel of the altar-fire, being originally, it may be supposed, not only the god, but also the victim. Once it covered the whole of England. As a fuel, it is still popular, especially if it is dry and old, and it is often available as dead scrub oak that has been killed by drought or caterpillar.

§ 23.

Oakbark was a medicine in the days of Dioscorides, conferring, in a civilised age, an intellectual sanction on its religious status. In our own middle ages, the small oak-buttons were esteemed for their content of "fire" or "vitriol". Our modern life is specialised in a way which hides from us these data which were the commonplaces of the earlier general education. We employ camphor and cinnamon to cure catarrh, and barely wonder what was their source. Exotic gums and oils and barks and balsams are still among our staple medicines. There are others used as varnishes. Few have been neglected in the rituals of worship, and in some languages the name of the principal local resin is the same as the word for "incense".

After all, the religious association is of less importance than the religious origin. The resin was the life-blood of something already regarded as holy, and the fact that on combustion it left almost no ash supported the conclusion that here was the holiest of all holies. So, in the Pyramid Text of Pepi, we have "Homage to thee, O Sycamore, companion of the god: Flame blazeth about it; *Fire burneth inside it*". For the gods of Egypt also were originally tree-gods. And when the life of the tree was gone? Then came the bee to its hollow, and homage was paid to a new marvel of the god.

§ 24.

To the English countryman, gum is familiar on the opening leaf-bud. There is gum, indeed, in the juices of almost all plants and trees, and there is a well-known gum that exudes from the branches of plums and cherries.

Yet the best-known gums are imported. Who has not heard of Gum Arabic, Gum Acacia, Gum Tragacanth, Gum of Bassora ("Hog Tragacanth"), Gum Kuteira or Gum Senegal? Then there are the gum-resins, well-known words again like ammoniacum, bdellium, euphorbium, sagapanum, scammony, asafetida, gamboge and myrrh. In the days of witchcraft, asafetida was a counter-incense: it dispersed spirits. Gamboge is the famous pigment, and it is used also for varnishes. It is the hardened juice of the Guttifers that flourish in Indo-China; it is collected through bamboo-pipes, thrust into incisions in the trunks of the trees. Myrrh can be obtained from any of a number of Balsamodendra. It is a perfume and an incense. It is also an unguent, for it was very early supposed that security against all kinds of cold and evil was obtained by being anointed with the holy products of the tree; and in the Roman Church we find a Holy Unction, the "seven holy oils" of the Egyptian priesthood, just as we find in witchcraft an oil that made a practicable vehicle of the broomstick. Myrrh is highly esteemed by the embalmer. In ancient Egypt, as described by Herodotus, the body cavity of an important subject was filled with myrrh. This people had "a persuasion that every disease to which men are liable is occasioned by the substances whereon they feed", so we are not surprised to find the phœnix feeding on two manifestations of pure fire, frankincense and amomum, and embalmed in another, myrrh. Its appearance was that of a golden eagle. When, after a glorious career of five hundred years, it died in Arabia, its offspring made certain arrangements which depended on the fact that the specific gravity of the phœnix was equal to the specific gravity

of myrrh. This is the most important item of the legend, since it demonstrates its conception by some early scientist. Herodotus thought it incredible, but set it down: "First he forms a ball of myrrh as big as he can carry; then he hollows out the ball, and puts his parent inside, after which he covers over the opening with fresh myrrh, and the ball is then of exactly the same weight as at first; so he brings it to Egypt and deposits it in the temple of the Sun". It is an allegory of Life, fuel, fire, gold and the Sun.

§ 25.

The true resins exude in hard tears from special resin canals, and they occur often in coniferous trees. They are found fossil or semi-fossil near the surface of the ground, or they flow from incisions in the trunk. Also they may be chemically extracted from the tissues. The most remarkable fossil resin is amber, and this has always been famous because it is so readily excited. To this substance the words carabe and ēlectron commonly refer. It came out of the sea, but it would burn and yield pitch so that its source was doubtful rather than its character. Its drops were the tears of the Sun-god's daughters, weeping for their brother. Roman ladies used it as a manicure: it was so interesting to rub it: and effeminate youths employed it to remove unwanted hair. It had the same chief source in the time of Herodotus as now, but he is very doubtful, and is not assured that there is any Baltic nor even any Eridanus, that is the Rhodaune which washes the west side of the free city of Danzig, a stream whose basin in Greek and Roman fable was populated by persons still wearing black for

Phaeton. Besides the alluvial pickings washed down by the river, amber is found in irregular nodules in the blue earth. It derives from many different conifers, and these can be traced in the beautifully preserved plant-structures. It may also contain numerous small organisms, and "flies in amber", as large as ordinary house-flies, entrapped when the exudation was fluid. Leaves, flowers and fruits are found in it, and Tacitus reports that some of the lumps even contained reptiles. Sometimes it retains the form of drops and stalactites just as it exuded from the ducts and receptacles of the injured tree. Amber ornaments have been found in Mycenæan tombs. An amber cup was found in England in a barrow of the bronze age. Their users almost certainly regarded them rather as amulets. Here again is the horn of the unicorn, purification by fire; and so, among the Turks who shared their pipes, the mouthpiece was of amber. Often in early literature bracketed with amber, we find bitumen, jet and ambergris. There is little connection except in their immediate sources and in the fact that they might all be fuels. Bitumen was a natural solid petroleum used as a cement in the time of Herodotus, as a depilatory in the time of Juvenal, and as a rust-proof in the time of Pliny. Ever since Phœnician days it has been employed in the caulking of ship's timbers, and in the sealing of coffins, mummies and wine-casks. The name "mummy" is simply the Persian word for Bitumen. Ambergris was the gall-stone of the spermaceti whale. It is a useful base of perfumes. Jet, "Whitby Jet", is a kind of lignite or anthracite from coniferous wood, particularly araucarian, that has been formed from wood carried out to sea to be embedded in the mud of the sea-bottoms, which, itself,

becomes a hard shale. "When heated", says Bede, "it drives away serpents; warmed with rubbing, it holds things to itself even as doth amber".

Kauri Gum and African Copal, both used for varnish, are semi-fossil resins. The first comes from New Zealand, and is found in any part of those islands where there has been a forest of the Kauri Pine. The lumps vary in size from that of a hen's egg to that of the head of a man. The best copal is found near Zanzibar, the fossilised lumps some three or four feet beneath the surface in now quite treeless districts, and a "raw" copal at the roots of now living trees, from the trunks of which yet younger copal may be extracted in just the same way as other "colophony" or "gallipot resin". In the East Indies there is an extraordinary natural method of extraction. Insects pierce the tree, imbibe the juice, and then transpire it so that it exudes over the entire body in individual cocoons which together form a communal tomb. The insect is termed Coccus Lacca (Lakh means one hundred thousand) because it is so numerous, and the resinous incrustation which is thus made to coat the twigs and young branches is termed a lac. The most familiar lac is perhaps shellac. Animé is the very agreeable lac from the locust-tree. These facts interpret a note of Herodotus which might easily be dismissed as a traveller's tale: "The trees that bear the resin are guarded by winged serpents small in size and of varied colours, whereof vast numbers hang about every tree". They saw the insects as serpents because that was what they expected to see: fire, feeding on fire.

§ 26.

It is the hard resins that are used for cements and varnishes; mastic, sandarach, the dammars and the copals. Soft resins, sometimes called "Oleo-resins", are fragrant with scent, and among these are turpentine, copaiba and frankincense. Modern medicine does not recognise any virtue in frankincense, but it continues to afford relief to the agonies of what Shakespeare called "the cold sciatica". Pliny commended it as an antidote to the "cold" hemlock, and Avicenna regarded it as a cure for tumours, ulcers and fevers. In the East, it has always been regarded as medicinal. It is a chewing habit in the Red Sea regions, and here also blazing lumps of frankincense are used as an illumination. If that is shocking, let it be remembered that at one time amber itself was sold as a cheap fuel. Do we not use coal so? Many resins have been falsely given the name frankincense, but it should be applied only to that olibanum which is the juice of styrax grown on cliffs of marble in Southern Arabia and Northern Africa. It is a milk which takes three months to harden, after which it is packed in skins and despatched to the sea for shipment to India where it is used as incense. It is not a name for the concreted turpentines of the Pinus Australis or the Norwegian spruce.

Styrax in various countries yields a group of balsamic resins known as Liquid Storax, Gum Storax, Benzoin and Gum Benjamin. Any soft resin containing benzoic or cinnamic acid is called a balsam. Other examples are the Balsam of Peru, Balsam of Tolu and Liquidambar. Liquid storax is a specific still against diseases of the skin.

In his glowing account of the fragrances of Arabia, Herodotus does not neglect the cardamoms. The word

cinnamon" usually refers to their branches, and "cassia" o the bark only. The fruits are used with spices and :hewed with betel. Anise, too, is a fruit. Musk and civet were animal excreta. It is the Malabar cardamom which nowadays is regarded as the best and true officinal, and the cinnamon bark of highest repute comes from Ceylon; but the amomum of the phœnix came from the Cinnamomum Camphora, and if we can now obtain camphor from the laurel, the laurel itself was the tree of Apollo.

§ 27.

With all these odours of Araby and spices of Malabar, the English epicure in firewood will prefer the perfume of the appletree. There is cedar, too, but that sighs for Lebanon, where it is worshipped, and for the plains of India, where it is the Tree of God. Like the ash, the applewood imparts to its flame colours vivid and fantastic as if it were retired ship's timber, cold-pickled in the salts of many seas. For breadmaking, they say that nothing beats the hawthorn. Even before Greek maidens carried branches of it in the nuptial procession and torches from its wood lighted the fires on the altar of Hymen, the scent of its blossoms timed the English year. Like the ash, or like the hornbeam which, said Evelyn, "Burns like a candle", it gives a hot, clear flame and will burn almost as well green as dry. All other woods must be kept under cover for a year, unweathered. With this provision, beechwood is an excellent fuel. Across the Channel, its nuts provide lamp-oil and cooking-fat. Our islands themselves are not rich in oil-bearing vegetation, but we have some gums and resins. Perhaps no tree has leaves of a more permanently sticky condition

than the water-loving alder. The author of *Sylva Florifera* (1823) says that the good housewife "is not unacquainted with a property in the leaves with which she strews her chambers before sweeping, for, when fresh, they are covered with a glutinous liquor that entangles fleas like birds in birdlime". In the Highlands, the tanning of hides provides a use, too, for the bark.

§ 28.

Resinous woods have this against them for indoor use, that they are not fully consumed. Their smoke is a cloud of fine particles of pitch. They throw out lively sparks and they create in the chimney an inflammable layer of tar. Poor folk who had to use birch or fir in the house would clear their chimneys by lowering a weighted rope and dragging a branch of evergreen through them. Mexican priests used this smut as a dye for their braided hair. Russian peasants, before the Revolution, used to spend all the little tallow or oil that they could buy at the shrines in the churches or before their ikons; their own illumination consisted of flaming billets of the Scots pine. These resinous woods, burned in the open, are in every sense splendid. The Scots pine or Fir is the ideal wood for the flambeau. It was with a flaming pine that Ceres walked abroad seeking Persephone. It was from the pith of pine that the figure of Osiris was modelled in the mysteries of Isis. A pine-cone tipped the thyrsus of the wine-god, and the Romans loved the flavour in their wine. The son of Coatlicue was born with a pine in his hand, spirally twisted like a barber's pole. Yet a roll of birchbark also makes a blazing and long-enduring torch it would be hard to beat,

and as kindling fuel it is indeed unbeatable. Carefully cut from the tree in a tubular form, it provided the earliest gown, and its warmth as clothing would be connected with its liveliness as fuel. "Dost thou know how thy garments are warm?" asked Job's friend, Elihu; but that is knowledge surely hid from most of us still: how many amateur gardeners, even in the Twentieth Century, make provision against the night-long radiation of heat into space? Or, indeed, how many housewives? The modern vine-grower does indeed cover his soil with flat stones. But the natural mistake would predispose the intelligent savage to employ bark as a renovator of his physical system also. Birchbark does, in fact, yield a fragrant oil useful to the tanner and to the kitchen wine-maker. But in old times, apart from building, the proper use of resinous wood was for the manufacture of pitch; and one example of the methods employed is still demonstrated by the Ainu of Japan, who collect the smut for their tattooings by holding broken pots over a fire of birchbark. Another of our resinous trees is the juniper. Its characteristic odour led to its use as a fumigant, and the Scots used to employ it for the smoking of hams. Religious experience showed the Greeks that this was the favourite perfume of the Furies, so the tree was consecrate to them, and its berries were thrown upon the funeral pyre. A wood that needs long preservation is that of the chestnut. It is a fuel for the November bonfire. It yields a roaring flame, disintegrating with small explosions. The commercial possibilities of these resins are small, or perhaps unexploited; yet in the Landes the timber turpentine and resin of the Cluster Pine is made to yield enormous wealth.

§ 29.

Mankind early noted that there was fuel both mineral and animal as well as vegetable. They were all fats and sulphurs. So the word Larch derives from the Celtic *lar*, or *fat*. It owes its very name to its resin. Like many another tree, it was burned to drive away serpents. Then there is a real vegetable wax. The white lines on the needles of the silver fir are stripes of wax. The shower of pollen from this tree is called by the woodman "the sulphur rain". In Pliny's time, a branch of this tree adorned the door of the house of death, not as an advertisement, like Thackeray's hatchments, but as a guard against evil. So many of our fellow-countrymen still use branches of the rowan and witch-hazel, with sprays of honeysuckle, as antidotes to witchcraft. They adorn both the farmhouse and the byre. If they have been applied too late, and the milk will not set, a rowan churn-staff puts all right again.

§ 30.

With all this identification of wood with fire, there was still the habit of thought, instinctively analytical, that required in every category a pair of opposite poles; it is an invaluable method of explaining abnormalities and exceptions. Here is the wood of poplar; it makes an acrid smell that debars it from indoor use even with modern ventilation; it will often obstinately refuse to burn; yet it is used for matchwood. Elder is the Eildon-tree of the old ballads. Placed on the hearth, it was held to invite Death. Elder-sap was one of the favourite ingredients of the witch's cauldron. They say it was an elder on which Judas hanged himself. Yet, by another

twist, as it faced another partner or opponent in the complicated dance of thought, since it was a cold, damp tree, its inner bark cured burns, and a gruel made from the buds cured fevers. One can imagine its supporters pointing with triumph to the fact that its hollow shoots were used for blowing up fires. So also elmwood was a source of controversy. There is the couplet:

> Elmwood burns like churchyard mould.
> Even the very flames are cold.

This prejudice may arise from the frequent hollowness of the elm, for witches and elves were hollow. So were dreams, and the connection is often explicit, as in the Aeneid. Those who knew not Virgil would not forget that the gallows at Tyburn were called "The Elms", for the elm was the Norman tree of "justice". The elm has done its best to deserve a bad name on its own account; there is no tree that has caused more human deaths by the incredibly sudden rupture and collapse of heavy branches. Then, too, it has been much associated with water. In London, it was used for aqueducts. I do not think that any of these are the main reasons: it is uncanny that the eye can follow the line of every branch of the elm through the trunk, where they seem loosely bound together, to the ground; it is ophic. When we sensibly put all these follies aside, however, we find that the secret of burning elm is to use cut logs of a moderate diameter instead of split pieces of older wood. It burns quite fiercely, and it is cheap enough when the Dutch elm disease has been at work. At the present time (1931) it is thought that the English elm is doomed to extinction, not only on this account but on account of the persecution by the larvæ of the goat-moth and of sundry beetles.

There is a similar tree in Japan, to which apparently no superstition attaches: the Ainu weave gowns from its bark; and in Europe itself in Roman days the elm was an object of the kindliest sentiment, for it was the living prop of the frequent vine.

There is controversy even about the yew. This hard, red wood was greatly esteemed by the bowyer and by the fletcher, but it lacks the resin (fire) of most conifers, and it has, literally, an evil spirit, a poisonous essence, called taxin, which has in our country, the mother of archers, given it priority even over the elm, the elder and the cypress as the tree of death. It decorated the shroud, it was borne by mourners, it was thrown on the coffin, the witches used it in their cold hell-broths. In East Anglia, it is still supposed to bring death within a twelvemonth to any house it enters. Yet it was blessed and burned on Palm Sunday. It was evergreen and symbolised Life. Its place on the grave was as a sentinel against witches. Its leaves were infused to make an ointment for the corpse as a safeguard against devils. The yew-lover would point triumphant in the spring to its yellow living smoke of male pollen. His antagonist would speak, with Shakespeare, of the double-fatal yew.

§ 31.

Among our ancestors, we find banked-up fires in the background of many a pleasant tale. In Caxton's version of the Beast Epic, the cat Tybert rouses a sleeping household with his cries. He has been caught by night in the gryn laid for Reynard. "The Priest took to his wife an offering-candle and bade her light it at the fire". Her view of this uninspired suggestion is not recorded.

Or we may go back some two thousand years further and watch Homer's ploughman carefully cover up the fire in the field before plodding homeward, and the aged servant in his manor hall, entrusted as a mark of favour with the care of the hearth, perform a similar final duty of the day. We do not find a record of any taboo that forbade a householder, if precautions had been neglected, to kindle his own fire—except indeed that a Hebrew might not do so, *may* not do so, during his sabbath; it was simply that in a community such an arduous and unnecessary act was unheard of. Fire was not to be refused save as the result of an official communal boycott. The simple goodheartedness of human nature is readily evoked when there is no fetish or taboo to replace it by savagery, and this made refusals very difficult even then. It was still more difficult to enforce a decree that was unpopular. When Clodius passed the interdict of fire and water upon Cicero, the populace ignored it. Yet this interdict could be made a singularly effective measure, and the almost incredible unfamiliarity of the layman with firemaking methods during the great Greek civilisation may be judged from the fact that when the corpse of Phocion was cremated, Conopion, a professional undertaker, had to bring fire from beyond the frontier. Such times are gone, but even in the opening years of the present century, the hostess kept spills of folded paper in a vase upon the mantelpiece for the convenience of smokers, and a small "by-pass" gas-jet burned in unoccupied rooms, for her own. Even now a pressing need of fire may create a certain conscious comradeship of manhood when one youth lights his cigarette at another's. Few would hesitate to ask such a favour, and none would

care to refuse it. In olden days, the conveyance of fire from house to house was so common that the fire-pan, or fire-bason, was one of the most familiar utensils. When the actual invocation of fire fell into disuse, it was thus that dead altar-fires were revived. The fire in which Mucius Scaevola burned off his hand to demonstrate his fortitude was in a fire-pan which had been brought to Tarquin for the conduct of a very different sacrifice. Clearly under circumstances of worship such as these, divine favour could hardly be augured from the mere appearance of a flame, so the good omen now consisted in its brightness and size. It was "a great and bright flame" that encouraged the reluctant Cicero to deal firmly with the leaders of the Catiline conspiracy. This was a normal omen. It was "a signal manifestation of preternatural agency" when Æmilius Paulus, sacrificing at Amphipolis, was interrupted shortly after the beginning of the holy rites by lightning, which, says Plutarch, "fell upon the altar, set the wood on fire, and completed the immolation of the sacrifice". A similar experience that befell Elijah is said to have been the direct result of a challenge and of a prayer. The shape and motion of the flame was anxiously regarded in the absence of any other sign. When, in order to rebuke the Magi who were sacrificing a horse to the Sun, Apollonius offered frankincense, "he watched to see how the smoke of it curled upwards, and how it grew turbid, and in how many points the flame shot up; and in a manner he caught the meaning of the flame, and watched how it appeared of good omen and pure".

§ 32.

Fire, then, was in very early days a reliable home comfort; and perhaps, as periods succeeded, there would have been very little variation in the methods of fire-making, had it not been for the hostile invader, the traveller in desolate regions and the seafaring man. In the time of Cleomenes, the kit of every member of a party detailed for an assault included a torch and a ladder, and watch-fires, kindled from the cherished source that the army carried with it, were made in the camp of nights. The modern Jivaros of the Amazon take kindling apparatus on their longer marauding expeditions, though it is true that they prefer when possible to carry smouldering ants' nests, which also protect them from insects. Probably a sailor, though his bark at prow and stern bore tutelary gods, would always scorn to carry fire. Virgil's Achates, thrown with Aeneas upon the shores of Libya, "first struck a spark from a flint, receiving the fire in leaves; round it he applied dry combustible matter, and instantly blew up a flame from the fuel". Such a feat betrays the expert, even in a warm country. Swift's Gulliver, beached on Balnibarbi, collected dry sea-weed and parched grass, for, says he, "I had about me my flint, steel, match and burning-glass". He had indeed an embarrassing wealth of fire-making material, for we find him later in the narrative employing "a pocket perspective". It must be admitted that he did not actually make a fire at all.

The only possible reply of the priest to the traveller was to make a distinction between the true fire and the base fire-substitute. A church that had already exorcised the Air, imparted holiness to Water—a sardonic parallel

with the routine of the Mexican witch-priests—and consecrated portions of the Earth, now solemnly blessed Fire. The rites varied in different cults, but all seem to derive from a communal festival of the solstices, celebrated from a time when at last all the fires of the tribe could be allowed to expire in the secure consciousness that fresh fire would certainly be forthcoming, the individual fires being then rekindled by brands from the rejuvenated common hearth. Progress, however, continued; and the remainder of this chapter is its narrative.

§ 33.

Fire from the friction of wood, one of the most primitive devices, may have suggested itself in many ways: from the forest fires—started by some stream of lava or some falling pumice or by the rubbing of dry, dead boughs in the breeze—from a sense that fire was hidden in the fuel, or—during the shaping of some wooden instrument—from the appearance of that smoke which was already associated in the mind with flame. So also the idea of fire-making by concussive methods may have been based on the sparks emitted on the chipping of stone. Where the bamboo is abundant—South-east Asia, the Indies and some parts of Australasia—fire is still produced by sawing the sharp edge of one split cane across the outer surface of another. In many islands of the Pacific, the hibiscus grows. Its wood is light and corky, and fire is made in these parts by a ploughing motion, a bluntly pointed stick being rubbed rapidly backwards and forwards in a groove in the flat surface of another piece. This groove must "run with the grain". In other regions, a drill-motion seems to have

been almost universal. The drill is a bluntly pointed stick, where possible of bamboo. This is rotated sharply in a slight hollow in the side of another stick, or in the edge of a flat piece of wood. In an advanced form—for only an expert can succeed by twirling the stick between his hands—a leather thong is pulled to and fro, the top of the drill then being held in a socket kept in position by the operator, often between his teeth. With the Eskimo and the Jivaro, the thong becomes the string of a bow, one hand being thus left free to take the socket. Indeed the application of the principle is in no way stereotyped: the bow may be a rib of caribou, and the socket may be one of its vertebræ; with the Jivaro, the socket is commonly a mere dip in the surface of a flat stone, and the stationary piece of wood is replaced by pith. The highest form of this device appears as the pump-drill of the Zuni and of the Onondaga, the stick being twirled with a screwing motion communicated by the up-and-down movement of a bobbin along a spiral thread. The most ancient form may be seen on almost any old papyrus: it is one of the Egyptian hieroglyphs.

§ 34.

What all these methods produce in the first instance is a small smoking heap of charred wood-dust which must be blown to a flame. Thus it corresponds with the tinder which is essential to the success of methods of concussion. The function of tinder is to capture and to nurse incipient fire which other bodies would only quench; and this means that it must be not only inflammable—whence its name—but also highly aerated. It must also be dry, or, where climate renders that a

counsel of perfection, it must be impregnated by nitre. The tinder of our grandparents consisted of charred linen rags, but many other materials have been commonly employed: dried moss, the down of plants, or even of birds, touchwood. Amadou was prepared from large fungi of the genus Fomes or Polyporus which are often found growing on the trunks of decaying trees. These were boiled, beaten, steeped in nitre, cut into slices and dried.

§ 35.

Because these materials will, in general, only smoulder, a secondary tinder, less ready to kindle, but quick to inflame, was used as an intermediate stage. Such was the "spunk" or "match", a slip of wood, or, later, of cardboard, which had been dipped in melted sulphur. Gulliver's "match" was one of these. Sulphur, of course, has stood for Fire from time immemorial, from the mariner's scar-fires of Homer to the hell-fire and brimstone of the Stoics and of the Roman Church. Now the methods of wood-friction were not unknown to the Romans, Pliny recommending especially the laurel and the ivy. In Italy and Sicily, however, rock-sulphur is plentiful. Sulphur, flax and tow were the staples of the incendiary. The Roman housewife obtained rock-sulphur at the door in exchange for broken pottery. They sometimes, therefore, combined the two stages into one operation, grinding decayed wood and sulphur together between two stones, much as if they were making flour. This combination is not unknown in the concussive methods, particularly in the colder countries. Thus the Alaskan and Aleutian bring together two lumps of quartz

which have been rubbed with native sulphur and direct the flaming sparks on to a tinder which consists of dry grass and feathers. Among the Eskimos, this method is slightly varied by substituting a lump of the native sulphide of iron for one of the pieces of quartz. In very hot countries, the problem is naturally easier, and the native will in some instances produce fire with the extremest nonchalance: in Burma, for example, by striking bamboo upon the broken edge of a pot, or, in Saigon, by a glancing contact of bamboo barks.

§ 36.

The original method of concussion seems to have involved two nodules of the native sulphide of iron, and this mineral thence received the name *pyrites*, "conversant with fire". In the Stone Age, a pointed flake of flint was associated with the mineral. At this time, the knowledge of what to Greek civilisation was a lost art seems to have been widespread. Probably with the idea of their utility after death, the two stones seem regularly to have been buried with their owner. Examples have been discovered still held in the hand-bones of skeletons which have lain undisturbed for three or four thousand years. Flint and pyrites are still in use among the Eskimos, who naturally try every method possible, and among the Fuegians.

§ 37.

With the coming of the art of smelting, steel displaced pyrites, and reigned almost unchallenged for some three thousand years. In the most highly cultivated communities, there was, indeed, no serious rival till the last few years of the nineteenth century, when phosphorus

sesquisulphide was employed for matches; and barely a quarter of the twentieth century had elapsed before the match industry was overwhelmed by a tax which octupled its prices and by the competition of the convenient petrol-lighter, the "last word" of the ancient method of flint and steel. In this device, the spark from a small cerium-steel wheel is shot with mechanical accuracy on to the wick of a pocket reservoir, the petrol vapour mingling with air at the surface of the wick to form the ideal tinder—an explosive mixture of gases. Artistically, perhaps nothing finer has been produced than the accessories of this method in the pre-petrol era. On these, the master craftsmen of a leisured age expended all their ingenuity and devotion. There is a collection of such material at the British Museum, and another, brought together by Mr. Bidwell, at the match factory at Bow. Here are steels engraved with the loveliest workmanship, often combined with ember-tongs, pipe-stoppers and cork-screws, or with hammers, gouges and strap-borers as in the ideal pen-knife of the modern boy. Here also, besides the normal English tinder-box, plain and sober like its Scandian brother, its only decoration a loop-handle by which it was hung at one side of the hearth as if to balance the fire-pan hanging at the other, may be seen the chased or inlaid locket tinder-boxes of the West European "sportsmen", tinder-tubes of bullocks' horn, armadilloes' tails, crocodiles' teeth, and tinder-pouches, from the ornamental "chuckmucks" of Mongolia to the coarse canvas bags of Afghanistan. There are Japanese tinder-boxes which were built on the lines of a wheel-lock gun invented in Germany about the year 1500. This was a gun in which a small piece of pyrites, held in a "cock",

was shut down upon the edge of a small steel wheel. When the trigger was pulled, a coiled spring was released, and this forcibly spun the wheel. The shower of sparks from the pyrites fell with cumulative effect upon a priming of gunpowder. After the consequent ignition and firing, the gun was re-loaded by replacing the powder and shot and by winding up the spring with a key. In its converted form as a tinder pistol, we find tinder, of course, in place of the powder. The sparks kindled the priming in the pan, and the ignition was communicated to a piece of amadou, held in a hinged tinder-holder which was enclosed within the barrel. The upper half of the barrel then flew up, presenting the smouldering amadou ready for use.

It is a matter of interest to English readers that the various parts of the world where the old forms of the flint-and-steel method are still in use import the flints or "strike-a-lights" from the flint-knappers of Brandon, in Suffolk.

§ 38.

The use of burning-glasses for fire-making must in any civilisation depend upon the progress of the arts. A lens of rock-crystal has been found among the ruins of Nineveh. As to Greece, lenses are the subject of a reference in this connection by Aristophanes, and Archimedes was familiar with concave mirrors. This man was a mathematician of great genius and the father of Mechanics. His reputation was enormous, even in his own age, and the theorems of his *Catoptrics* gave rise to a legend that he had successfully used optical methods to destroy the Roman ships in that naval action at Syracuse where he met his death. This legend has

probably some factual foundation. In the Artillery Museum at Stockholm there is an ancient burning mirror which the Swedes in some such fashion seem certainly to have employed. Even during the decline of Greece, there were treatises on optics, written for example by Diocles and Ptolemy, and since fire-making by this method was peculiarly susceptible to a religious interpretation, the method was not lost. It is said that the Virgins of the Sun in Peru kindled the sacred fire with a concave cup of gold; and of such a custom in Greece we have irrefragable evidence: when the undying fire, in spite of all precautions, had been quenched—as at Athens under the tyranny of Aristion, or at Delphi when the Medes demolished the temple, or as in the Mithridatic and Civil wars, when even the altars were broken down—

> "In re-kindling this fire", says Plutarch, "it is esteemed an impiety to light it at common sparks or flame, or from anything but the pure and unpolluted rays of the Sun. This they usually effect by concave mirrors of a shape formed by the revolution of an isosceles rectangular triangle. All the lines from the circumference of a mirror such as this meet in the centre. When it is held in the light from the Sun, all the rays collect and concentrate at this one point of convergence: here the air will now become rarefied to fire, and will kindle any light, dry fuel that may be applied to it".

§ 39.

In our own climate, the lens as a burning glass is a child's toy; but in China it is in everyday use, and it was welcomed throughout Western Europe in the seventeenth, eighteenth and nineteenth centuries. It was an honourable stage in the search of the chemist for high

temperature. Shakespeare's Falstaff complacently complained that Mistress Ford's glances "did seem to scorch me up like a burning-glass".

> "By means of large burning-glasses", writes Lavoisier, "a degree of heat is obtained somewhat greater than has hitherto been produced in chemical furnaces, or even in the ovens used for baking hard porcelain". "But", he adds, "these instruments are extremely expensive and do not produce heat sufficient to melt crude platina; so that their advantages are by no means sufficient to compensate for the difficulty of procuring, and even of using them. Concave mirrors produce somewhat more effect than burning glasses of the same diameter, as is proved by the experiments of Messrs. Macquer and Beaume with the speculum of the Abbé Bouriot; but as the direction of the reflected rays is necessarily from below upwards, the substance to be operated must be placed in the Air, which renders most chemical experiments impossible of performance with this instrument".

By this time, at least in England, some ingenious artificer had put upon the market such articles as a burning lens inserted in a cigar-holder, combined with a pipe-stopper, the whole mounted in steel. It was at this time that Priestley, having acquired a new burning-glass twelve inches in diameter and twenty in focal length, operated with delighted enthusiasm upon a medley of substances, one of which was the calx of mercury. This was the classic, though not the first, occasion on which he obtained oxygen.

§ 40.

The alchemists, of course, had used it long before. Paracelsus makes it a climax in his ladder of "degrees of fire":

"One is the live, flaming fire which reverberates and calcines all bodies. Another is the fire of the candle and lamp, which fixes all volatile bodies. Another is the charcoal fire, which cements, colours and purges metals from their scoriæ. . . . Another is the fire of a roasted iron plate, on which the tinctures of metals are probed, which also is useful for other purposes. In another way" (mixed with powdered sulphur?) "scobs, or alkali, of iron produces heat, in another way, sand, in another, ashes, in another, the balneum maris, by which many distillations, sublimations and coagulations are produced. In yet another way operates the balneum roris, in which take place many solutions of corporeal things. Otherwise again acts the venter equinus, in which the principal putrefactions and digestions take place, and in another way operates the Invisible Fire, by which we understand the rays of the Sun, which also is demonstrated by a mirror, or a steel plate, or a crystal, and displays its operation and effect, concerning which fire the ancients wrote scarcely anything. By this fire, indeed, the three principles" (Fire, Water and Salt) "in any corporeal substance can be separated on a table. Of so wonderful a virtue is this fire that by means of it metals are liquefied, and all fat and fluxible things—indeed all combustibles—can be reduced to carbon and ashes on a table and without fire".

In the same place he makes it clear that to melt up iron filings with the "fusion mixture", still common in our laboratories, he uses a tigillum and a blast furnace. Then for gentle courses, as when he makes imitation pearls, he uses diffused sunlight or the warm nook behind his furnace.

Where only four degrees of fire are considered, they are the Balneum Mariæ (the water-bath or steam-bath, woman because water, and Mary because most excellent), the bath of ashes, the sand-tray and the open fire.

§ 41.

When a gas is compressed, its temperature rises. The caloricists of the eighteenth and nineteenth centuries said caloric was squeezed out of it. This is the basis of a method which has been for many centuries employed by inhabitants of Indonesia, where they make fire with a type of syringe. Such an instrument was patented in England in 1807; but three years before that, the principle had been independently discovered on the continent. In those air-guns that the Germans call wind-books (because they are charged with compressed air merely by opening and shutting them), the act of opening compresses a spiral spring, one end of which, formed like a piston, bears on a closed cylinder of air. A workman, whose name has never appeared, had the curiosity to build one of these with a glass window, so that he might see what happened in the compression-chamber during the compression-stroke. He found that the lubricant took fire. He then succeeded in "capturing" the fire by the simple expedient of fixing a piece of tinder in the head of the piston. Biot, a leading European savant of the time, filled the compression-chamber with electrolytic gas and repeated the experiment. The destructive force of the explosion was terrific. We understand now that the gas did not merely explode: it detonated. It would be impossible now to say whether "Mollet's Pump", "Lorentz's Light Syringe" and the "Pneumatic Tinder-Box", which appeared shortly after these experiments, were due to the science of the anonymous artificer or to the art of the Southern Seas. The European examples were commonly of steel, and the motion of the piston forced air through a very finely holed rose on to a morsel of

amadou. Their superiority to the earlier and more picturesque Oriental fire-syringe lay chiefly in the fact that the latter had to be pulled to pieces after each operation, the fragment of tinder being shaken out from the small cavity in the piston-head where it lay; for these earlier instruments consisted merely of small tubes of bone, wood, horn or metal, which were entirely closed at the lower end. The piston was usually of hard wood, but this also might be of horn or of metal. The Bidwell collection contains a fire-syringe, made in Sarawak, where the cylinder was of thick solid lead, bound with a brass collar; slung to it are a slender wooden cleaning-rod and, for tinder-holder, a small crocodile's tooth.

§ 42.

This method is a reminder that any physical alteration of state "wants change", as they say in the shops: it is accompanied by an absorption, or by an emission, of heat. So also is any alteration of chemical identity. Because of the suggestion of a paradox the most striking are those that involve water, especially if they happen under ordinary, everyday conditions without any flavour of the laboratory. The Egyptian priests appeared to make fire by spells "alone", a fact we may perhaps read in conjunction with § 13. One of the earliest chemical inventions for fire-making depended on the readiness with which a mixture of carbide and finely divided metal can be oxidised by the ordinary moisture of the atmosphere. Homberg made such powders by heating Prussian Blue, or by roasting alum with starch or with sugar.

§ 43.

A century later, Döbereiner similarly prepared his "Pyrophorus", and the continuance of his researches on finely divided metals led him in 1823 to the beautiful achievement of the Döbereiner Lamp. This employed the fact that gases may be absorbed into the outer surface of metals, the intimacy of their mutual contact leading to their chemical union, with a consequent emission of heat and the phenomenon of ignition. A small glass jar, in which a plate of zinc was suspended from the lid, was provided with a reservoir of acid. When a tap in the lid was opened, the acid streamed into the jar and attacked the zinc. A certain amount of zinc passed into solution, and the acid yielded an equivalent quantity of hydrogen. This passed through the tap as a jet and impinged on a surface of spongy platinum or spongy iridium. When the tap was closed, the evolution of the hydrogen continued until the acid was forced back into its reservoir after the manner of the Kipps gas generator.

§ 44.

The progress of electricity gave rise to certain rather obvious and very cumbersome devices by which a spark was made to ignite inflammable gas. These never became very popular. The discovery, by Berthollet in 1786, on the other hand, of potassium chlorate (or "oxymuriate") had an enormous influence. Berthollet showed that, in the presence of strong acids, chlorates would oxidise combustible bodies. In 1805, Chancel applied the discovery in a new invention, the Oxymuriate Match, and this was introduced in England as the "Instantaneous Light Box". It was a small tin, containing a bottle of

sulphuric acid and some minute matches, the heads of which were compounded of potassium chlorate, sugar and gum. There were usually arrangements to prevent stray drops of vitriol from falling on the spare matches and igniting the lot. When one of these matches was momentarily dipped into the acid, the head immediately "took fire". This invention was widely used for some twenty-five years, the only objection being to the nature of sulphuric acid, since this liquid was liable to spirt, when the essentially explosive reaction took place. The introduction of its use into the manufacture of fireworks proved even less fortunate. We shall see later that all ignition is essentially explosive, since there can be no flame without a prior mixing of mutually reactive gases. Its explosive nature does not challenge attention, however, except in cases like this where the consequent expansion of the gases finds some employment which is not merely "beating the air". The Promethean Match of Samuel Jones, patented in 1828, was an application of the same principle. It was a spill of paper. Sealed in one end was a small amount of the dried paste and a small glass capsule of acid. Flame was produced by any suitable means of fracturing the capsule. Potassium chlorate entered also into the composition of the friction-match of John Walker, a pharmacist of Stockton-on-Tees. It was a wooden splint, three inches long with a firm head consisting of potassium chlorate, antimony sulphide and gum arabic. These ingredients were mixed with water in an intimate cream and dried on to the matches. In 1826, Walker sold the first of his shilling tins, each containing one hundred matches and a piece of sandpaper. The purchaser was to nip the head of the

match in the sandpaper and then jerk it out. Samuel Jones, at his "Light-house" in the Strand, adopted this invention also, for it was not in any way protected, and it was copied by numerous other traders. It was Jones who altered the name "Friction-lights" to "Lucifers", and the latter name became very general. In 1829, Isaac Holden showed that a small addition of free sulphur to the other constituents much assisted the ignition. Other matchmakers similarly used camphor, and this idea developed into the general impregnation of the wood of the splint with suitable combustible substances, such as paraffin.

§ 45.

The peculiar properties of yellow phosphorus (§ 13), at first called phosphorus mirabilis, or phosphorus igneus, were made generally known in Europe by Brand at Berlin in 1669. Krafft, who bought the secret, exhibited the substance in England in 1677. It produced a profound impression. In 1678 and 1680, it was prepared by Kunckel and by Boyle. It was not until 1775, when Scheele extracted it from bone-ash, that it became a commercial possibility. The earliest attempt at an application to fire-making was to rub a particle between folds of coarse brown paper, the smouldering edges of which were to be used in the then familiar way to ignite the old sulphur-tipped "spunk" or "match". This method was dangerous to the fingers and made few friends, so that for some years phosphorus remained a plaything or a scientific resource used, as Lavoisier used it for example, in igniting explosive mixtures of gases. About 1780, however, came the "Phosphoric Taper" (or "Candle") or "Ethereal Match". This was a slim glass

tube containing a little phosphorus at one end, which was sealed. The insertion of the taper closed the tube at the other end. About one inch from the sealed end, the tube was cut round with a glazier's diamond so that the phosphorus might be quickly and cleanly exposed. It remained an expensive toy. Six years later, an Italian, whose name has been lost, brought out in Paris the "Briquet Phosphorique". It was a small tin box containing some tiny wooden sulphur matches and a bottle which was coated on the inside with phosphorus. The method was to dip a match into the bottle and withdraw it with a little phosphorus adhering to the head. Similar contrivances immediately brought out in London were called Pocket Luminaries. A "Portable Firebox" illustrating this principle may be seen in the museum at Saffron Walden, but this also contains a piece of cork on which the match should be rubbed. The "Phosphorus Bottle" of Cagniard de la Tour was only different in that his phosphorus was first partially oxidised. In 1805, according to Nicklés, friction-matches containing yellow phosphorus were made and sold in Paris. Darmstädter mentions that Derosne made them there in 1816. Sauria, often quoted as the first maker, does not seem to have made them till 1830. Innumerable types were put on the market later, but they are of interest now only to the collector. Not only were they dangerous to their possessor, but their manufacture became definitely immoral when it was found that the fumes of slowly oxidising yellow phosphorus produced a dreadful disease. Workers having carious teeth were found to be subject to the insidious phosphorus necrosis, which began as a masquerade of toothache and ended as a sort of leprosy of the jaw.

§ 46.

Phosphorus may be deprived of most of its unpleasant qualities, however, by conversion into the red form, or by chemical combination with sulphur. Red phosphorus was discovered by von Schrötter in 1845, and Böttger suggested that it might very well be employed for matches. It was utilised in this way for the first time ten years later, when Lundström brought out the "Safety Match", which has still a great vogue. The head of the match consists of potassium chlorate, sulphur, gum and glue, and the striking surface is an emulsion in glue of red phosphorus with pyrolusite or with antimony sulphide. The binding ingredients vary in different "makes". The materials quoted for the head of the match may also be used for the striking surface, as with Camaille's match (1852), provided that the materials quoted for the striking surface are then used for the head of the match. The "Allumette Androgyne", brought out in 1859 by Bombes, Devilliers and Dalemagne, and copied by Field in 1882 as the "Hermaphrodite Match", was a splint with a head at each end. Each head contained one of the complementary preparations, and for use the splint was broken in two and the heads were rubbed together. The value of the sulphide of phosphorus is that it has made possible the manufacture of a friction-match which requires no special surface. About 1820, at Erfurt, small glass tubes were sold which contained equal quantities of sulphur and phosphorus carefully fused together; splints were to be dipped into this product and then ignited by friction. In 1864, Lemoine lixiviated this product in the laboratory and showed that it was for the greater part a pure chemical compound. In 1898, Sévène and Cahen

took out a patent for its use in making matches, the English rights being purchased by Bryant & May, a firm which has since generously presented the formula to the whole industry. It was the great success of this new friction-match which enabled the British Government in 1910 to prohibit the further use of yellow phosphorus. Even this prohibition could not revive its use.

§ 47.

These, then, are the methods of fire-making. Clearly they all are mere transitions in form of the energy expended in the method. Chemical energy, radiant energy, mechanical energy, these have gone into the till, and flame has been bought by barter. Nothing has been lost. "It is easier", said Roger Bacon, "to make gold than to destroy it". The bush burns, but it is not consumed. The fire is not quenched.

CHAPTER III.

THE PRIMAL MATTER.

He sang how in the mighty Void, the seeds of Earth and of Air and of Ocean, and of Fire—that pure thing—ranged themselves together; and how from these principles all the Elements arose, systematically cohering in the tender globe of the World.

—*Virgil's Sixth Eclogue.*

I might say Element—but the word is over-worn.

—*Shakespeare's Twelfth Night.*

§ 48.

Primitive Man recognised four large regions, each suitably ruled and inhabited by creatures appropriately equipped. Later, he became dimly aware of the four different physical states. Early philosophers noted the continual interflowings of these four states, and sought a common denominator in a primal matter which might also in some systems be an ultimate matter and into which the sage might remelt its derivative forms; thus eliciting some benefit very tremendous but extremely vague, vague as this original Chaos itself. It had a name however. As the perfumer expressed the fragrance of blossoms into an attar, so the Magi hoped to attain the Perpetual and Divine Quintessence of the World. The theory of the four elements was accepted by the European philosophers as a hypothesis of purely physical significance. That hypothesis has never been overthrown. It is true that like a bad debater and his claque Renaissance philosophy claimed to have confuted it; but what was confuted was something which the earlier thinkers had

expressly denied in a denial so important that it was the very basis of their reasoning. Philosophy did not wait until the Seventeenth Century A.D. to learn that there was water-vapour in atmospheric air! Men of the calibre of Anaxagoras and Aristotle did not believe that wood and stone and iron were identical in substance! Differences in identity were fundamental to the hypothesis; for it was not born in the minds of the Eleatic school which believed that there could be no change: it was a product of the Ephesian teaching of endless alteration and perpetual flux.

§ 49.

Saying Earth, Water, Air and Fire where we say Solid, Liquid, Gas and Energy, they distinguished the states not so much by form and visibility as by density. Heat rarefied Earth to Water by melting it, Water to Air by boiling it, and Air to Fire in a manner described already in § 38. Believing, most of them intensely, that a simplicity of order was Heaven's first law, they conceived that Fire was something as much more tenuous than Air as Air was than Water or as Water was than Earth. But they did not test this theory by comparing these last two ratios. Stone is about two and a half times as heavy, bulk for bulk, as water. Some solids are actually lighter. Yet as between a liquid and a gas the corresponding ratio is enormous: it is realised best perhaps by recalling that a "head" of 34 ft. of water will balance the whole height of the atmosphere.

Experimentalists or not, however, they call for our unstinted and reverent esteem. They had not seen, as we have seen, the electronic glows in evacuated discharge-tubes; yet they felt that they had seen pure Fire, the only

element that ever might be seen pure: they identified it in Sunlight, in that strange electric energy that pulses through the ether inactive and uncashed until by contact with matter it is realised in golden coin as Radiance. Let us offer them our tribute! It is one of the most beautiful identifications of Fire with Energy that only differences in the wave-lengths of ethereal radiance should distinguish Radiant Heat from other forms of Energy with which the modern world is so familiar that this table is no novelty, though it may be a useful reminder:

Wave-length of ethereal radiance	Title by common association
Below 4 ten-millionths of a metre	Ultra-violet & X-rays
From 4 to 8 ten-millionths of a metre - - - -	Light
From 16 to 4,096 ten-millionths of a metre - - -	Radiant Heat
Measured in metres and in hundreds of metres - - -	Wireless

The deduction that this radiance, the only pure thing known—since it avoided even the minor contaminations suffered by rain—proceeded from an immediate source still more worthy of veneration, was a deduction buttressed by all religious custom and prejudice. It was a fallacy of which Anaxagoras was not guilty, but his "heresy" led to his banishment. He said that the Sun was only a glowing stone; and, as for the Moon, that was an earthy body, intersected by ravines, shining by

reflected light. Among contemporaries, Democritus alone supported him. These thoughts were not new to Democritus, for he had travelled in the East, but they horrified Socrates and, averse as this man was from the study of physical science, his outraged piety inspired him, as we have seen, to construct a treatise differentiating sun-heat from that of the domestic hearth—which, it is true, was not the point at issue. Socrates' disciple, Plato, was to offer the same grateful homage to the heavenly bodies; and to Plato's pupil, Aristotle, they were still something to be spoken of only in language of enthusiastic and passionate love. Even as late as Plutarch, the sun's oblique orbit about the earth was explained in terms of a purpose "to dispense his light and influence in just shares to the whole creation".

§ 50.

It is to Anaxagoras that we owe not only this hypothesis of the Four Elements, but the modern conception of the molecule. Two streams of thought flowed from his teaching, and they flowed in paths which did not meet again until the nineteenth century. We must follow each in turn.

"Anaxagoras of Clazomenæ", says Plutarch, "was the first of the philosophers who did not refer the first ordering of the World to fortune or chance, nor to necessity or compulsion, but to a pure, unadulterated Intelligence (*Nous*), which in all other existing mixed and compound things acts as a principle of discrimination, and of combination of Like with Like". Knowing what Plutarch did of the Egyptian religions, it is a magnificent testimony to his judgment that he does not under-rate

the step from Thoth to Nous and from Sympathetic Magic to the Attraction by Similitude of Substance. Consideration will show that the apparent conflict of this principle with modern teaching in magnetism and electricity is largely illusory and referable to terminology. The very great proportion of truth in the principle was to exercise the mightiest minds for many centuries. Probably the last occasions under which it was formally invoked were in Hahnemann's homeopathy and in Lavoisier's explanation of the tendency of metals to form alloys and amalgams. Picturesqueness has always been inseparable from it. Plutarch tells how jaundice might be cured: the sufferer was to gaze steadily at the large yellow eye of the stone-curlew. Paracelsus taught that "God has ordered it that the poison of the plague should be drawn out by dried toads, for then one evil thing serves to extract another". Francis Bacon believed that the principle was "most conspicuous in small and subtle portions of bodies, because greater masses of things follow more general and catholic forms". He instances the cohesion of bodies, true even of bubbles growing under water, but marked in solids, and demonstrated as true of liquids by the roundness of their drops. He repeats an ancient belief that salt is more soluble in salt water than in fresh, and makes a note to try if sugar is more soluble in sugar-water. As an example of what he means by "a more general and catholic principle" which would mask the influence of the Attraction by Similitude of Substance, he instances Gravity; and if Gravity could only be overcome, some very remarkable effects of the other principle would ensue:

"We had in use, at one time, for sea-fight", he says, "short arrows which they called sprights, without any other heads save wood, sharpened, which were discharged out of muskets and would pierce through the sides of ships where a bullet would not pierce. But this dependeth upon one of the greatest secrets in all nature: which is that similitude of substance will cause attraction where the body is wholly freed from the action of gravity: for if that were taken away, lead would draw lead, and gold would draw gold, and iron would draw iron without the help of the loadstone. But this same motion of weight or gravity, which is a mere motion of the matter and hath no affinity with the form or kind, doth kill the other motion, except itself be killed by a violent motion, as in these instances of arrows; for then the motion of Attraction by Similitude of Substance beginneth to shew itself".

§ 51.

Now certain substances attracted water and finally dissolved into liquid. Paracelsus says of "watery minerals" or crystallised "salts" (of which he recognised, besides nitre, "more than one hundred"): "they must be kept in a warm and dry place and guarded well from the Air in wooden chests. They must not be placed on glass, stone, or metal. By these they are dissolved and turn into Water". This, said Boyle, "is nothing but a solution made by the watery steams wandering in the Air". Elsewhere he says, "Indeed, it does but arrest such of those as chance in their passage to accost it. . . We may allow that they may be the more firmly arrested by a kind of precipitating faculty that the magnet" (i.e., the attracting body) "may have in reference to such effluviums"—and having acknowledged a "faculty", he feels that he may just as well resign his thesis, so that he adds, "Nay, I

dare not deny it to be possible but that in some circumstances of time and place one of our magnets may, as it were, fetch in some steams as would indeed pass near it but would not otherwise come to touch it". Nowadays we say that the proportion of water-vapour in the air is low in the neighbourhood of such a substance except in so far as it is maintained by the approach of fresh supplies of water-vapour. So that Boyle was not in any way extravagant in the quotation which has been made.

§ 52.

The principle of Like to Like became embodied in the common outlook and acceptances—note only the urchin's immemorial joke of "Wood to Wood"—and is frequent in Literature, particularly in regard to Rank and Marriage. The now hackneyed fatuity of "Sweets to the Sweet" appeared, perhaps first of all, in Shakespeare. There was an application also to emotions, mental qualities and "immateriate virtues"—as Bacon calls them —which was not at all metaphorical, or strained; nor was it far-fetched like the Chinese proverb "Truth is drawn to the true". Bacon himself was far too true a scientist to exclude thought and emotion from a survey of reality. Instance one engaging parallel between Bacon and a popular superstition recorded by Mark Twain and still believed in Lincolnshire.

> "We are a little doubtful to propound it", says Bacon, "it is so prodigious: but it is so constantly avouched by many, and we have set it down as a law to ourselves to examine things to the bottom and not to receive upon credit or reject upon improbabilities, until there hath passed a due examination. This is the sympathy of individuals: that is that in the parts of things that have once been contiguous

> or entire there should remain a transmission of virtue from the one to the other . . . and so of a stick of elder, etc., that if part of it be consumed, it will work upon the other part severed".

It is actually, of course, an aspect of what has been called "Homeopathic Magic" and it may be found in the works of Marcellus of Bordeaux, who doctored the court of the first Theodosius. Huckleberry showed no similar diffidence in propounding his cure for warts, but this is coloured also by the ancient identities of blood, life and fire, blood calling to blood in kinship, or from the ground to heaven, blood flowing again in a murdered body to greet and convict the murderer who bore blood on his hands, blood drawing upon the murderer the accusative direction of the flames of the funeral fire. "It will have blood", groans Shakespeare's Macbeth, "they say blood will have blood".

> "You take and split a bean", says Huckleberry Finn, "and cut the wart so as to get some blood, and then you put the blood on one piece of the bean and take and dig a hole and bury it 'bout midnight at the cross-roads in the dark of the moon, and then you burn up the rest of the bean. You see, the piece that's got the blood on it will keep drawing and drawing, trying to fetch the other piece to it, and so that helps the blood to draw the wart, and pretty soon off she comes".

In Chicago, only fifty-six years ago, there was a disinterment for the purpose of burning the lungs of a consumptive woman who was supposed to be drawing her relatives after her.

§ 53.

It is not to strain the imagination to suppose that Anaxagoras, like Bacon, noted that damp places dried

inward from the edge, and observed the growth of icicles, frost-patterns, stalagmites, stalactites, and the terraced masses of crystal cubes which grow beneath the surface of evaporating brine. It may be assumed that he had seen the separation of a mixture of oil and wine, that he had noted the resistance of a stone to fracture. But then, these were not the crucial examples. The great force of his hypothesis dwelt, after all, in the ancient recognition of the fact that our immediate neighbourhood in Space consists of three great segregated masses of substance, namely Air, Earth and Water. Bubbles always toiled to the Air, streams to the Ocean, "their Mother and their Tomb", solid matter downwards; the slight extension to Fire was warranted by every prejudice of human kind, and, to boot, by the behaviour of the upthrust flame of fuel.

Thus, from the principle of Like to Like came the hypothesis of the Four Elements; but this principle, by itself and unqualified, would lead to a stagnant system of four masses of pure substance. Hence an opposed stirring must also be at work, so that the four materials in unceasing motion modulated one into the others. Nothing was without fire, save in an extreme indigence of nature; nothing was without water, for there was nothing without form; nothing was without air, for its surface particles wore and weathered into air; nothing was without earth, since all things had weight. It was, on a short view of a limited change, not the character but the proportion that varied; the variation being the resultant of two, three or four attractive processes, contemporary and opposed. In the system of Empedocles, the natural attraction of Like to Like is called Love, and

the energising principle opposed to this tendency to settlement is called Strife. Love is Osiris, and Strife is Set or Typhon, whom Julius Firmicus Maternus well identified with Heat, since "Iron came forth from Set", and it had magical powers. In Plato we find this Strife as one act of God who thus wound up the Clock of the World, for, as the Elements were refractory, God "mingled them all into one idea, joining them by force, since the different would not mingle with the same". Thus it became the destiny of the mixture, by the attraction of Like to Like, to "return at length to the first and best disposition of its nature". So Paracelsus had in each element an Archeus or satrap whose business it was to promote this separation, and "separation", he says, "is grounded in Heat". Plato's enthusiasm for mathematics is common knowledge. He designed atoms for each of the four elements, choosing for the purpose from geometry such three-dimensional forms as would build together into masses. The cube form for Earth was ready to his eye in the crystals of common salt, and he devoted other forms to the other Elements. But alas, his crystal atoms had brittle edges and were always, by the principle of growth and change, in the process of mending, so that "there are many kinds of fire", "numerous kinds of water", "different kinds of earth", all produced from constituents. Paracelsus in loyal echo writes that "Nature is like a painter who from some few colours, paints an infinite number of pictures, no one exactly like another; only Nature paints living pictures". The Four Elements, for Plato, were limits existing only at the poles of change: "The element itself", says Paracelsus, "is never seen by any". As for the Nous,

Plato has not disposed of that by naming Deity. There is a "mother and receptacle of all created things. We cannot term it either Earth or Air, either Fire or Water—nor any one of their compounds, nor any one of the constituents from which they were produced; but we should not be at all wrong in calling it an invisible and shapeless essence, which receives all things and has a certain share of intelligence—though how it possesses intelligence is a matter very obscure and hard to understand". Aristotle had the reputation of reading in the library when he should have been listening to Plato's lectures, so that it is not a matter for surprise when we find in his system rather the Nous of Anaxagoras than the God of Plato. for the Nous of Anaxagoras was less personal than the Thoth of Egyptian religion, the Intelligence or Emanation of the Creator. In the basis of Aristotle, which was destined to be the orthodoxy of the Middle Age, the primal matter of Plato has been denuded of intelligence and oscillates inanimately under the influence of four qualities. He called it Hylë, a word cognate with the Latin Silva in its sense of deal or material. Every substance lay at some stage between hot and cold and at some point between wet and dry and was subject to ceaseless change. The Four Elements again were limits having no actual existence. Elementary Earth was a limit where the hylë would have been perfectly cold and perfectly dry. Water bore the same relation to cold and wet, Air to hot and wet, Fire to hot and dry.

§ 54.

Thus early in the history of thought we have the sense that a lump of matter is a miniature of the World.

We shall see later that the idea of the microcosm was of the utmost importance in the building of the foundation of modern chemistry. The cosmogony of Aristotle varied little from that of his master. Plato had placed the earth in the centre of a spherical World, separating the first two elements created, Fire and Earth, by two others, Air and Water, and this "as near as possible in proportion to each other so that Fire should be to Air as Air to Water" and so on. The World was thus "an animal, destined to comprehend all others within itself . . . artfully made to provide itself with nutriment through its own decay . . . its soul at the centre but interwoven throughout from the midmost to the very extremities of Space". Circling round the earth as Fire, "the chief idea, indeed, of Deity", in successive orbits raced first the Moon, then the Sun, then the planets. How vividly and materially these concentric spheres were envisaged by these classical thinkers may be realised when we read that Aristotle conceived the flickering light of the Aurora to be due to their friction.

A catholic conspectus of classical views would give us, first, the Earth, essentially cold and weighty, but variable in constitution, being comparatively hot and choleric in some localities and moist in others; upward through this came airs, venting themselves in Virgil's phrase—more elegant than Pliny's reference to Charon—at "the breathing-holes of grisly Pluto" (but they were sluggish, misty airs), Ætnean fires (but they were pitchy, smoky fires) and water at the sources of brooks which hurried to the sea.

Then Water, which also varied from place to place, being stagnant, or aerated, or medicated; upward through

this came bubbles and mists and a coolness which promised water to the weary traveller long before he saw it; as there was water in the air neighbouring it, so was there air in the water, and in mining lore it was believed that suffocation was impossible near the surface of subterranean water provided that it was flowing.

Then Air, the variations in which from place to place were of enormous importance to mankind "crawling between heaven and earth" and therefore one of the specialities of the physician; the first medical treatise was entitled "Of Airs, Waters and Places", Boyle wrote another, and Shakespeare's Bānquo, like Ovid, attributes a taste in airs to summer birds of passage. Gratified explorers would name a pleasant strand "buenos aires". Upward through the Air rose matters containing a competence of Fire sufficient to overcome the downward pull of the grosser aqueous or earthy content. The Lower Air was full of such pendencies. Here were "intermediate spirits, neither precisely good nor precisely evil". The purest Air, or air containing Fire (a natural confusion) might ascend above the Middle Region—the field of clouds, a favourite perch of good spirits, sometimes indeed the seat of an angry god, the cockpit of meteoric disturbances, the source of that most violent cold which was positive energy, not a mere absence of Fire—and merge in the Empyrean.

Then came Fire. Here dwelled the bird of Jove. Here were gryphons.

§ 55.

Since Fire would ascend still further, even beyond the orb of the Sun, there was a feeling that the purest

fire was not only free from water and from earth and even from air, but that it was non-corrosive, and in its highest form, luminous only, debased by excess neither of heat nor of cold. So Heracleitos had written, as if in anticipation of the Socratic distinction of radiance from fire struggling in matter, that the most perfect soul was "a dry light".

The recent craze for the solarisation of the body is a reminder that 300 years ago it was sometimes as Light that fire was regarded as a preventive of the Plague: when the steward of the monastery of St. Gall interviewed a patient, "he placed a very bright light between them". Boyle thought he had distinguished a concrete example of a heatless light in the "unburning flame" of his "aerial noctiluca"—an old name for the Moon—the luminous mist rising into the air from slowly oxidising phosphorus. He played with stoppered bottles of it under the bedclothes and ruminated the possibility of a night-clock in which dark hands were to move over a luminous dial. Not until his laborant had burned a couple of holes in his apron was he disillusioned. Nor was he without ample grounds for his belief. He, like the alchemists before him, had prepared the phosphorus from an excrement which, as was common knowledge, the radiance of the heavens would sweeten into nitre; what wonder that he identified the two heatless lights!

For heatless lights, as they appeared, were known. There were stones and gems that seemed to "shine by their own nature, like the Sun"; and even our modern watches and clocks, if they do not use phosphorus any more than they use radium, do at least employ the depilatory sulphides of the alkaline earths.

§ 56.

In the brief flowering of philosophy in the thirteenth century, we find that it was as Light once more, but actually under the name of Light, that Robert Grosseteste envisaged the primal matter. Writing as a matter of course in Latin, he used *Lumen* to indicate the source, and *Lux* to denote the substantial principle. The source was self-diffusing (compare "The Day *Spring* from on high") and the substance was self-organising. The diffusion of the light being the same in all directions, it generated a sphere, becoming rarefied as its distance from the source increased; finally, the sphere of light having reached a certain critical and limiting diameter, it shrank towards the centre and condensed into material substance. Like Empedocles in another age, he conceived of light as being composed of quanta, or packets, or little atoms; and he explicitly interpreted his Light as an offspring of Motion, which is Energy.

§ 57.

In Egyptian mythology, sight had been a roving ray, proceeding from the eye of the seer. It was thus, in one story, that Ra, the eye of the Creator, had achieved a separate existence; for during one of his long absences, the Creator became accustomed to other arrangements. Greek philosophy found in sight an illustration of the principle of Like to Like, and with Plato, for example, sight was held to be due to the union of sight-rays, "the pure fire within us, flowing through the eyes", with the image-rays, coming from the object seen. "All such phenomena", he said, "necessarily result from the affinity of the external and the internal fires". Ptolemy was to

preach the same theory, five hundred years later. Another line of thought made Light not so far perfect that it could not be vitiated—if only because the mind can imagine every gradation between Light and Darkness. The theory that colours are simple stages in this gradation is due to Aristotle, who thus dispensed with red, regarded by Plato as a primary, and also drew the memorable corollary that fishes see only in black and white, because they have no eyelids. Bacon, although he describes Colour as "Light, varied", does not by any means follow Aristotle blindly. He does not agree that the more brilliant colour of birds, as compared with beasts, is due to their living more in the sunlight, but attributes the difference rather to a greater fineness of texture in quills than in skin. He understands that light is refracted by prisms, by gems and by dew, and he assigns a similar refractive power to the rainbow—which he takes to consist "of a glomeration of small drops", but he is puzzled by a difference which manifestly exists between colours of this category, which are parts of sunlight, and the colours of flowers, which are pigment.

§ 58.

It was still a novel advance, in Bacon's time, that the thermal significance of colours should be discarded, and we can appreciate that, when we reflect that it still persists. In our own times, from motives of delicacy, Maori ladies have tattooed the lips, and European ladies —from what motives who shall say?—have reddened them. In Ireland, red hair has an equal efficacy with fire as a protection against the Shee, and this connection is known to all schoolboys; nor need one go to Ireland

to find a very general association of redness with a choleric constitution. Bartholomew, a contemporary of Grosseteste, saw the rainbow red on top, in sympathy with Fire, followed by bands of Blue, Brown and Green for Water, Air and Earth; and, if such a spectrum did not commend itself to the more serious of the later alchemists, they still saw in each colour a specific power and virtue, allotted them the traditional thermal quality and applied to them the principle of Like to Like. The red centaury had a warm nature, and the white lily a cold. So, with Paracelsus, the fume of sulphur bleached red flowers by attracting to itself the flowers' fire. Even Bacon recommends that the wool used in massage should be scarlet. Is the present age quite innocent of the belief of a special warmth in red flannel?

§ 59.

Thinkers on these subjects had to explain first the hot red of the fire on the hearth and in the body, from which the coupling of heat with redness originated, secondly the elusive red of the rainbow, thirdly the red of vegetable pigments, in which the fire was potential and not made manifest, and fourthly the red of roasted rust, the burnt crocus of Mars, "in which", said Paracelsus, "no heat, but a sort of dead splendour inheres". This was the residual fire, the incombustible sulphur which was in another context called Salt or Ash and at one time at least—for he advances other explanations also—this in his view held the secret of colours. It would be a fancy of the utmost foolishness to pretend that the identification of redness with heat—even among the medieval philosophers—had anything whatever to do with the fact that

the red rays are neighbours of the heat-rays in the key-board of ethereal vibration. It was simply that a red-heat was the highest temperature generally known. The alchemists with their terrific furnaces of sulphur burning in nitre obtained temperatures undoubtedly much higher. We can now obtain white heat, or "blue heat"; for solids at a temperature above 1600°C. are "candent", emitting light of every wave-length in the spectrum. As they cool, the dominant radiation moves away from the blue, until at about 1000°C. it has almost left the yellow. "Cherry redness" follows, and at 600°C. the body has only a dull glow. On further cooling, darkness supervenes—but the radiation continues. This is not "heatless light", but "lightless heat". Experiments with this "dark heat", as it was called at the beginning of the nineteenth century, laid the foundation of modern physical chemistry; and we may claim with pride that, if it was Descartes who analysed sunlight into the spectrum, it was Bacon who suggested that Radiant Heat was "the concomitant of Light, not the effect of it".

§ 60.

But Chemistry was waiting also for the atom, and this also it owed to a stream of thought emergent from the wisdom of Anaxagoras:

The Nous of Anaxagoras differed from that of some succeeding systems in being omniscient and omnipotent and in being especially concerned with forms of Life. Yet the only manifestation of this solicitude is Motion. The originator of the principle of Like to Like, therefore, actually did not teach a subjective attraction: this, as

Bacon points out, would mean a prior subjective perception: he taught rather that the segregation of matter was a shaking down into place, a process that was never finished, so that there was no such thing as a pure element. In this shaken mass were the spermata, or seeds, or minute constituents of things. The atom, or molecule, of Anaxagoras was, in brief, a miniature, and the disentanglement of order from chaos was a series of mechanical processes.

§ 61.

As revised by Empedocles, the Sicilian poet-prince, the urbane Boyle or Berthelot of his time, this atomism amounted to little more than a theory of emanations from the surfaces of things. He conceived that the body, and more especially the organs of sense, were permeated by fine channels or pores. Leucippus, however, pointed out that bodies throwing off a flux of infinitesimal particles must be similarly constituted throughout, and that if the organs of sense were of the nature of honeycombs or sponges, such also must be the universal constitution of matter. Further, assuming that there could be no motion without vacuum, Leucippus uttered the entirely novel idea that there might be space without matter. His friend, Democritus, now questioned the necessity for the existence of the Nous. If there were a soul of the World, it consisted only of the fiery spherical atoms which were its constituents. They fell in infinite number through infinite space for ever downwards. The heavier overtook the lighter, giving rise to collisions and pressures which produced infinite worlds. In relation to heavier bodies, the lighter appeared to move upward, and, relatively, were forced upwards. Thus Democritus correctly explained

an effect of gravity on a false basis, and in the eyes of Aristotle the two fallacies in this description were sufficient to condemn the whole; he rejected the entire theory by drawing attention to the convergence of falling bodies toward the centre of the World. This involved his rejection of the atom also, but he continued to teach that motion in space was the fundamental change, and that the process of realisation, the transformation of power into act, was Motion.

§ 62.

Epicurus, a contemporary of Aristotle, mended the damaged structure, and the theory of Democritus was now re-stated with especial insistence on Vacuum and the Atom. Time and Space were infinite: so was Matter, or long ago it would have been dispersed into the Void. Time also extended backward, so that all possible combinations of the infinity of atoms must have occurred infinitely often. The most stable among these combinations persisted and were extant; the rest tended toward dissolution and a fresh series of creations. In deference to the Peripatetic criticism, the atoms now moved with equal velocities, a speed inconceivable, and with a convergent cant; they had in common also the property of perfect compactness and indestructibility; but they differed in size, in figure, and in weight.

§ 63.

Great men have been followers of Epicurus and his philosophy, and in the seventeenth century of our era—for much of the best of the Renaissance came from this source—it was revived and codified by Pierre Gassendi.

It seems to have inspired his pupils to great literature, just as it inspired Lucretius, but to literature of a merrier sort. Molière and de Bergerac were two of these. Hear Cyrano make fun of the Earth as the Aristotelian "centre" : he moved about the surface of the Sun, he says, "without finding it any more uncomfortable to walk with my head than with my feet, because it had no *centre* . . . and since I was far outside the active sphere of our Earth, it was impossible that I should still have weight". It was because Aristotle was still the orthodox philosophy, and because it was very dangerous to oppose it, that Cyrano thus taught Physics through Irony. Seventy years after his death, however, Swift could write quite seriously of the moons of Mars that they were "governed by the same law of gravitation that influences the other heavenly bodies". Newton's work had intervened.

§ 64.

When Newton had come to consider the World, he saw God, and he retained this vision. When he had come to consider the new Epicureanism, he saw the atom. Supporting its adoption were the mathematician's predilection for the particle, and also two advances, then recent, in the theory of Heat. The thought that heat in a body was an expression of the motion of its particles was more than a century old. In § 53 we found it in Paracelsus, who believed for example that mercury was liquid because it had an innate heat that kept it so. Descartes, again, was clear that the sensation of heat arose from a kind of motion communicated to the nerves, and Bacon defined heat as "a motion, acting, in its strife, upon the smaller particles of bodies". Thus Heat was

Empedocles' principle of disturbance. The second advance, however, had been made in Newton's own lifetime by his correspondent, the illustrious Hooke, who employed this same motion to differentiate states of matter. "The cause of fluidness", said he, "I conceive to be nothing else but a certain pulse or shake of heat; for heat being nothing else but a very brisk and vehement agitation of the parts of the body (as I have elsewhere made probable), the parts of the body are thereby made so loose from one another, that they easily move any way and become fluid". It is to be noted that "the parts of the body" have not suffered any change in themselves and are, inferentially, still solid; so that in the century of discussion which followed Newton on the molecular constitution of matter, and in the kinetic theory of gases, enunciated by Bernoulli in 1738, the distinction of states lies not in the particles, but in their behaviour: how could a single particle be fluid? Such a question was merely an attractive "query" to be placed among Hooke's notes for analytical examination in that future leisure that never came. Thus, then, Newton on the atom: "It seems to me probable that God, in the beginning, formed matter in solid, massy, hard, impenetrable, movable particles, of such sizes and figures, and with such other properties, and in such proportions to space, as most conduced to the end for which He formed them; and that the primitive particles, being solids, are incomparably harder than any porous bodies composed of them; even so very hard as never to wear or break in pieces, no ordinary power being able to divide what God Himself made one in the first creation". Newton thus re-affirms a spiritual principle which has created and now pervades the World.

A little later, a Jesuit monk in a monastery at Ragusa was writing that the atom was a mathematical point, the centre of radial forces; but Boscovitch was before his time, and in 1829 we find Henry still quoting Newton's description of the atom with the fullest approval. Fifteen years later still, however, the new science of electricity having made marvellous progress, we have Faraday speculating that the atom may be an atmosphere of forces, grouped about a mathematical point.

§ 65.

If it is a matter of some difficulty to bring the history of the atom up to the present day, that is due to the speed of our progress, not to any doubling or turning on the part of the brilliant investigators of the subject. Moreover it is being carried out as happy, international "team-work", reminiscent of that other age of intensive research of which Samuel Johnson wrote: "A man who is growing great and happy by electrifying a bottle wonders to see the world engaged in prattle about peace and war"—except, indeed, that it is the warmonger who is now the exception, and that the man in the street will discuss with his cronies the latest news of the constitution of matter. It is true that the man in the street is generally loosely informed that "matter is made of electricity", and that this cannot be said with strict truth since, on the ionic basis, the charges on the negative electrons, planets of the positively charged nuclear proton, sum with the nuclear charge to zero; so that the atom is not "made" of these constituents, but of the Force that wrenched them apart out of non-existence and holds them separate: but the electron and proton, being no longer "mass" in

the old connotation of the word, may now be imagined as similar in nature to the particles of light postulated by Empedocles, by Grosseteste, and by Newton. The particulate character of Light was denied in Newton's time by Huyghens, who insisted that it was propagated by waves, and this theory of light was set on a firm basis by Young, Fresnel and many others, above all by Clerk Maxwell. The heat of the contest between the two theories was due to the fact that they were both true; and it is of interest to the present chapter that it was from a study of Radiant Heat that Planck deduced the most recent re-statement of "atoms" or "packets" or "quanta" of light, which are now to be called "photons". It seems from the recent work of De Broglie and Schrödinger that whether one is dealing with the photon, the electron, or the proton, its particulate character is due to the behaviour of the wave in which it moves as a centre of special disturbance. In this last analysis, matter is not different fundamentally from radiance: they are cognate works of Energy, reaching out in Ether.

What, then, is Ether? Or is this beyond our Thought? What is Thought? And what are we, who, in the midst of all these vortices of motion, detach ourselves as alien "immateriate virtues" to examine them? If we have found the primal matter, what is the primal cause, and what the ultimate effect? Has any positive alternative yet been offered to that primitive faith and fumbling expressed by that great artist who wrote "The Book of Job"?:

> "I go forward, but He is not there; and backward, but I cannot perceive Him; on the left hand where He doth work, but I cannot behold Him; He hideth Himself on the right hand that I cannot see Him.

"Lo, these are parts of His ways, but how little a portion is heard of Him!

"But He knoweth the way that I take: when He hath tried me, I shall come forth as Gold".

Yes, since an intuition, inherently poetic, commonly precedes the factual proofs of Science, some may see in these hings, leaping from peak to peak of lofty conception, he emanation of the Creator—the Unicorn, Thoth, the Nous, the Word which was like a flame, so that perhaps he ultimate extreme of poetic beauty burns in the conception that the Word became flesh and dwelt among us—'He dwelleth with you and shall be in you"—the outer Heaven born on the hearth of an inner Fire, fitfully uelled in the hearts of men.

CHAPTER IV.

THE BAND OF UNION.

Permeating all entities, giving to all things life and consistence, binding, moving and filling all things, Immense Renewer in Nature's charge.

—Benedictus Figulus (*A Golden and Blessed Casket of Nature's Marvels*).

This blood is the Balsam of Balsams, and is called the Arcanum of Blood. Keep this occult. It is a great secret in medicine.

—Paracelsus (*Concerning the Preservation of Natural Things*).

So in the centre of the Earth there is a sun of the Earth, which by its perpetual motion radiates heat outward towards the surface of the Earth. It is tempered by the Water, which pervades and refreshes the Earth.

—Seton (*The New Chemical Light*).

§ 66.

However much in advance of his time a writer may be, because he uses its language he must employ its concepts. Thus it comes about that Shakespeare is a magnificent mirror of the fluxive controversies of his era. Through the greater part of his work there broods, like a deep diapason pedal, a mood of depression. He is haunted by the creeping stealthiness, the continuous and untiring rat's tooth of change. Age, decay, the incidence of Death, these make of Time an enemy that is the subject of some of his most fiercely eloquent apostrophes. Time was the great Remover. Life was Time's fool. Now Time was considered by his scientific contemporaries, like Bacon, in its effects; just as they considered the effects of moisture, of heat, of pressure or of atmospheric

exposure, so they looked for the results of Age. They were all manifestations of Empedocles' principle of Strife, the rôle of Energy in that separation which Paracelsus said was grounded in Heat. But Energy, like a lonely player at a game two-handed, had another rôle; and when at last Shakespeare's faith triumphs over his apprehension, it is in the very terminology of Empedocles: "Love's not Time's fool". The undying Fire possessed also all the attributes of balm.

So, although the thoughtful savage knew quite well that fire burned wood, he yet hardened the end of his wooden spear by thrusting it into the fire; and we, whom the last chapter has made familiar with Fire made manifest in heat, disintegration and strife, must now observe his appearance not only as the first principle of organic growth, but even as the prime cause of cohesion. The two colleagues of Fire were naturally still essential. Matter was triune, and there could be no life nor consistency if one of the trinity was absent. To that extent, each of the three, Soul, Spirits, and Body, Fire, Water and Salt, was a preservative, a balsam, and a principle of cohesion. The necessity of Fire, Water and Salt to Man —who was continuously losing all three—argued through the principle of Like to Like as cogently as through the principle of Loss or Wear that such was the triple constitution of his nature. "Man has need of ardent foods for the sustenance of his Sulphur, he wants moist foods for keeping up his supply of Mercury, and he eats Salt to cherish his nature of Salt". Then, because this senior member of the family of microcosms was made of Fire, Water and Salt, so were all the others. We must first glance, then, at this matter of microcosms.

§ 67.

One of the tricks of witchcraft was concerned with the mutilation of a waxen doll. It is an example of that "sympathetic magic", that sense of a relation between Like and Like, which is one of the bases of primitive thought. It was played during at least 1700 years of our era, and for at least sixty centuries before it. It was based on a lively and persistent belief that there was a subtle rapport between an object and its image. It was the rational basis of the Second Commandment of Moses, and it led to other, greater issues: with ideas in their minds about the architecture of the World, men began to see small models of it everywhere. In our tongue, these miniatures have been called both "Little Worlds" and "Microcosms", some of our contexts conveying a consequent inference of perfection, though very many do not. Nowadays we use a similar analogy to illustrate ideas about the atom.

In Babylon, Man himself was a microcosm, and his future might therefore be read in the stars, his own stars being hidden within him and therefore somewhat inaccessible. In medieval times, it was often his body cavity—taking, in thought, the place of the entrails of the augur's sacrificial victims—that was the little world. This left his head to function as an independent microcosm, as in many of the most poignant passages in Shakespeare's delineation of the fallen Richard. Very early indeed, the family also became a microcosm. So did the State. So finally did anything that had a central fire or life. So finally, therefore, did all things without exception, since each possessed a name and a secret faculty for being itself, and not a mere aggregation of its

contributing constituents. Even Deity had a secret sacred Name: hence the hold of Isis upon Ra. In Augustan times a priest was executed for divulging the secret name of Rome. When a witch-novice purported to sell her soul to the Devil, she was held to have resigned her central life because she had parted with her name. To this extent she became "hollow".

This central soul was not the animistic spirit that like a hermit-crab, or like a caddis-worm, moved drolly from house to house: it was inseparable from the normal existence of the thing it labelled. If it were removed, only a husk, a shell, remained. This had a travesty of existence only when informed by witchcraft. On the other hand, the soul itself survived the destruction of its home, and the shadow of the very home itself survived, for it might be recalled in memory or in dream. Both soul and home were necessary, however, to the normal existence, and thus the sacred central fire of life was the supreme balsam or preservative or bond or band of union.

It was because Hales had the curiosity to measure the weight of the souls of a number of chemical substances that he was the first man, so far as we know, to prepare oxygen; but that happened only two hundred years ago and may be regarded as the chemist's climax to the long growth of the idea through sociology, cosmography and medicine. We must first learn to endow all substances with a central hearth, to think of the World, and of the mimic worlds, as of eggs, to link high spirits in the body, a sturdy upthrust of sap in the plant, a brisk distillation in the alchemist's alembic, and April weather in the atmosphere, without any reservation or sense of incongruity; for we must accept in every microcosm not

only the inner fire or soul of life, but also the water-cycle of those spirits whose loss robbed the body of its form, the fountainous motion consequent upon the impregnation of the passive water by the male fire. It was a typical paradox that Adam (the Soul) carried his own invisible Eve (the Spirit) hidden in his Body.

For, be it noted, the first rendezvous of the forest-beasts was not the fire but the salt-lick of the riverside. The nucleus that built a village was not the common hearth—yet a distant achievement of conscious co-operation—but the spring. The first parliament of gossips was not the ingle-nook, but the well. A very useful mnemonic for our present purpose inheres in the Roman microcosmic device of Central Heating described by Seneca. The fire or sulphur in the cellar is the Soul. The hot and moving vapours in the pipes are the Spirits. The spirits are vehicles of fire, messengers of fire, mercuries. The fire goes out, and they are spirits no longer. The water boils away, and energy has no medium. But when we have Fire and Water together, then the Soul expresses its energy by means of the Spirits.

§ 68.

First we return to the communal fire, burning night and day in some public place for the public convenience near the communal reservoir or well. The value of the shared boon in the cementation of the state need not be laboured. Here, too, we see a circulation, for those who took faggots to their tents aflame brought contributions of fuel which replaced them. The contribution likewise partook of the nature of religious ceremonial. Thus annually on the middle day of Ab, itself named the *Heart,*

or Hottest Month, of the year, the early Hebrews held their Feast of Woodcarrying. Among our own islands, Inismurro, near the Sligo coast, may still exhibit to the visitor the frame of a primitive hearth. It is contained within an old church, built in later days inside the ancient cashel. In America, among the Natchez (who inhabited what is now Louisiana) among the Aztecs, the Mayas and the Peruvians, the summit of the national pyramid was employed. This *ku* was commonly the centre of a reversed amphitheatre of terraced palaces and temples of the rain-gods; it was the seat of deity: and its walls were adorned with pictures of the Feathered Serpent to whom the virgin attendants of the hearth were sacred. In Egypt also the public fire burned in a temple; Wallis Budge interprets much of ancient Egypt, and inferentially its influence on Mediterranean civilisations, in the light of present-day Africa, so that even had not the custom been world-wide we should learn without surprise of the care of an undying fire among the Damara, tended by the daughters of their chiefs or priests.

There were two aspects of Fire in its relation to the communal soul; one was growth, the other, synthesis; they both tended toward cohesion. Just as now in Damaraland, departing scions take with them a burning brand from the old hearth to the new home, so the sacred fire in the prytaneum of the early Greek state was the origin of all the sacred fires in the prytaneums of its colonies. In Greece it was so greatly reverenced that the life of the state hung upon it in intimate dependence. State and prytaneum were synonyms. So, when a colony took its departure for some Ionian isle, the sober leaders would attend in solemn procession to receive fire from the

parent altar of Hestia; this, in the new prytaneum of the infant state became its own sacred fire and life and identity and soul. It was a birth, even if it was also a propagation by fission. We find the fruits of this idea also in the amenities of warfare: just as the early Hebrews had carried the Ark into battle, just as medieval warriors were to bear the Host, so no Greek or Roman army ever crossed the frontier without a portable prytaneum, whereon fire from the nation's heart burned night and day.

In more established times, Athens claimed to have taught fire-making to her neighbours, probably as being the city of the oldest tribe—"We are the school of Hellas"—but in early days it was believed that she would never realise her potentialities until the twelve tribes of Attica brought each its brand to a common altar of Athene Polias. It is written that under the leadership of Theseus this they actually did, and Athens was now stronger because she had collected herself. This principal fire that was formed was not merely a token of unity; it was itself the causal and consequent strength of that unity. When Greece as a larger whole collected herself, all this took place on a larger scale, a central hearth of the Federation being constituted at Delphi at the site of the famous blower of natural gas. The islanders of Ionia made one of their own at Delos, in connection with which we also read of a common treasury and a common sâcred water; Puteoli, a later Delos, boasted also a mephitic exhaust from the central fire of the Earth.

This synthesis began a fresh circulation: from the state fire, new fire was annually fetched to revive the village prytaneums. Similarly the Persians preserved

these local fires in every small community. So did the Latins. The synthesis, or collection of strength, at Rome itself started when the three curiæ merged their principal fires. When Rome subdued Greece, marvelling at the folly that lived so intimately with advanced knowledge, a knowledge of optics and mathematics above all, they found a model of this fire-synthesis, or synœcism as they called it, in the lens and concave mirror, instruments which caused the hot rays of sunlight to collect themselves at a common central hearth. Their word for this was *focus,* so that modern optics actually owes this word not to one of the clever races of ancient times but to their dunce. The French, by their use of *foyer,* have inherited not only the word but the idea.

It must not be forgotten that immoderate centralisation defeated its own good ends. The central hierarchy became too rich. There followed all the pomp and banners of a gorgeous ritual that smothered the poetry of its source. Sober reformers saw that Fire and Water in excess were the principle of putrefaction. Here then was all the beauty of decay, art decadent indeed but wonderful. The pious Jew, paying his annual pilgrimage of Passover to the great central sanctuary at Jerusalem—where alone this sacrifice might be made—would nod in wonderment in recollections of the Golden Calf as he regarded the great bronze "sea" of sacred water held high above his head by twelve great bronze oxen whose chines were its radii. Jehovah had deserted Israel before for similar excrescences of priestly importance. Just so, in later days, Æschylus conceived that when a city lay in ruins, it was thenceforth deserted by the gods, though indeed Virgil interprets this view as signifying that the

§ 69.

Neptune had a similar "sea" in the Acropolis—he had made it for himself, for it was salty. As far as possible, however, we find that the ancient city tended to be built so that its citadel—the last refuge of the besieged—enclosed a spring. So also, in Rome, we find the Capitol standing a siege of six months before it was betrayed. Here also was the Salt store. In general, however, all the civil and political interests grouped themselves round the Regia, the sacred centre and abode of Vesta, at once a prytaneum, a temple, a tribunal, a town-hall and a public lounge. In the Greek cities the prytaneum was moreover a hearth in the sense associated with the home, and the orphans of public men or of men slain in warfare might be publicly adopted and housed there. It became in this way the home of the eldest son of dead Demosthenes. When the fire was by any chance extinguished, this superstitious race to which the most unimportant happening was an omen, fell an immediate prey to dread, depression and horror. The connection between heaven and earth had been broken: it must reverently be restored.

All these conceptions may be found in the history of our own era. There is a very impressive similarity in certain customs of the North American Indians. For example, the Assinais and the Maichas were of common origin and used a common prytaneum; this was of circular—or, shall we say, of firmamental—form like the Roman temple of Vesta. The Natchez regarded themselves as having sprung from the Mobiles and applied to them for fire when by any chance they lost their own. In the eighteenth century, though the tribes had each a

central fire and possibly also a company of vestal virgins, their several strengths were collected in a common prytaneum at Onondaga. "It was a saying among our ancestors", said an Iroquois chief in 1753, "that when the fire goes out at Onondaga, we shall no longer be a people".

§ 70.

If the prytaneum was the essential nucleus of the state, so was the hearth of the home. We have spoken of the domestic importance of the salt-cellar, which, among the superstitious Romans at least, received attention from moist fingers as often as anything unlucky was mentioned; just as among the superstitious of our own day we see the touching of Wood. But Water held an honoured place, though not the prime place. The principal apartment had an opening in the centre of the roof called Compluvium. It was also termed Cavum Aedium, the Hollow of the Shining Ones, though doubtless the beautiful origin of *aedes* was generally forgotten. Derivatively, it meant hearth, altar, sanctuary, temple, and at last merely dwelling. The firmament or roof of the house sloped towards this opening, so that the rain-water fell into a cistern, commonly marble, in the centre of the floor. This water was necessary not only for the more obvious purposes of drink and cooking and the bath (or latrine, a name which with a genteelism worthy of our own suburbs they transferred to the water-flushed sewage arrangements), but it was used for lustral purposes even in the very worship that was principally associated with Fire.

For Fire came first. Eskimo children realise this when they insist on enclosing a lighted oil-dip in the small

snow-houses which they make at play. The sense of property, too, is vested in the hearth, and that sustains the Englishman as he stands with his back to it and lays down the domestic law. In the East, where inheritance fell to the youngest son, he was termed the fire-keeper, the heir. Now in the nearer East, the worship of household gods has been habitual for long ages. The principal cause of dispute between Laban and his son-in-law was that Rachel had stolen the household teraphim; the principal reason for the avoidance of consequent bloodshed was that Laban and Jacob had both worshipped before them. Reconciliation in the open wilderness was followed by joint worship before a heap of stones, which stood as token for a monolith. The monolith itself, the backbone of Osiris, enters Hebrew worship as the gold-encased ephod of divination, and both ephod and teraphim appear as heresies in the devotions of the temple; for though the Jew would have repudiated with contempt the worship of Wood or Fire—and, cleanly as he was, refused to adopt cremation—the notions of Blood and Gold are found in his religion everywhere.

Among the Romans, the identification of hearth and home included the household shrine of the domestic gods, who were to the family what the public Lares and Penates were to the state. This constituted the primacy of Fire, that it was an integral part of domestic piety. The shrine stood originally in the outer room, but when the hearth and the kitchen were removed to the back of the house and meals were served upstairs, the shrine followed the hearth. It was the place of the morning assembly of the household when the paterfamilias offered sacrifice and prayer. It was again the scene of a formal supplication

before each meal, and before dessert the food that had been placed before it was shaken into the fire during a short and reverent silence. The intimacy of the connection between the father and the hearth as house-band can hardly be exaggerated. It had already developed without loss into the worship of ancestors. When Ovid was banished, the fire was allowed to expire; and it was to the cold ash that his wife, he assumed, would weep and pray. It was a conception as much Greek as Roman; the burned and banished bones of Phocion were clandestinely buried beneath his own fireplace. The connection between the shrine and the hearth was equally intimate: if eating took place upstairs, then the shrine was carried up; and, since the actual hearth was lacking, a token or representation of the hearth was burned before the shrine. It might be anything that burned, and was usually a taper.

It is significant, too, that in the shrine the mid position was occupied by Vesta. The mother of Romulus was a Vestal Virgin, but Vesta stood for domestic chastity. It was in order not to offend Vesta that the new-made bride was lifted over the threshold. Right and left, supporting Vesta, were two Lares, which in earlier times had been boundary or property gods, or two Penates, previously the larder-gods. On all domestic festivals of every kind, these images were crowned with garlands and received especial offerings. The hand that touched the altar must be innocent like that of Phidyle whom Horace tenderly admonishes in connection with the festival of the New Moon. Rosemary and myrtle he suggests for the garlands; and for the gifts "a consecrated cake and crackling salt".

§ 71.

In the shadow of these gods was sacred shelter, an influence that persisted wherever food or drink or salt was shared. The focus of this generous principle was at the hearth, and it issued from the gods of the hearth. It was in deference to these gods, and also, as among the Greeks with their Zeus Xenios, to some particular god, that the stranger or refugee might find sanctuary in the ashes of the domestic hearth or at the horns of the temple altar. Homer describes the entry of Odysseus to the hall of Alcinoüs : proclaiming himself a suppliant and calling down blessings on the family, he asked for help in regaining his own shores and then dropped to a sitting position in the ashes of the fireplace. The cups they had been about to drain to Hermes the assembled guests poured now instead upon the ground—a libation to the Divine Friend of Strangers in whose good providence a mortal man might at some auspicious time play host to angels, unaware. They treated him royally. It was an offering to the god. It was to an age that had forgotten this charity of feeling, this noble pride in kindliness that is one of the natural endowments of manhood, that John preached, as if in new doctrine, "Whoso hath this world's good and seeth his brother have need and shutteth up his bowels from him, how dwelleth the love of God in him?" His hearers knew the Inner Hearth. They did not need the gloss "bowels of compassion".

Such, then, was the hospitality extended to an unknown and dishevelled stranger among Homer's Phæacians, who, though they "loved not strangers over-much", had no charity organisation society. Nor is this mere mythological rhapsody belonging only to an early

literature of escape. There are dozens of such stories in the classical historians. Thucydides and Plutarch both narrate the charming story of Admetus and Themistocles. It was in historical times that Themistocles fled to Admetus, a royal enemy whom earlier he himself had treated with most grievous ignominy. "Yet in this misfortune", says Plutarch,

> "Themistocles put himself at his mercy and became his humble suppliant, and this after a manner differing somewhat from the custom in other countries: for, taking the king's infant son in his arms, he laid himself down at his hearth, this being the unique and sacred manner of supplication among the Molossians, a manner of prayer indeed that might not be refused. And some say that Phthia the queen instructed Themistocles in it, and herself disposed him with her small son before the hearth. Others allege that Admetus himself prepared this rite as a sort of stage-play in order that he might be religiously obliged to refuse Themistocles to his pursuers".

§ 72.

If over-synthesis and city-life to some extent destroyed hospitality by making it, in the common view, sheerly impracticable, much remained. When John was preaching from Patmos, Juvenal was writing in his ninth satire with reference to Rome: "Oh my little Lares, that call me master, whom shall I supplicate with a fragment of frankincense or meal or a poor garland? Whom shall I corner for something to ensure my old age against the beggar's mat and crutch?" The person of no fixed abode was now actually taunted with his "Firelessness". Fire had become a commodity and slaves might be seen running home with their purchases, not for haste's sake,

but because that kept the fire alight. The little gods were dead; yet some of their influence remained. Though swarms of little Cæsars joined them, and all alike became mere dolls, it was still felt for example that divine vengeance fell on the householder on whose hearth an enemy committed suicide. Cicero had often considered this method of annoying the first Cæsar; it is an idea that had a direct counterpart in the ancient Chinese revenge of suicide on an enemy's threshold.

Ideas derivative from the hospitality of the hearth largely survived then the destruction of their origin. The "token" conception was world-wide, and we recognise it at once as a harmless example of sympathetic magic. A suppliant might carry a branch of olive, but in his hand—not bound about his brow, a sign of triumph—or he might embrace his patron about the knees. These tokens originated in the facts that olive was an unctuous wood and that the knee was a favourite haunt of its possessor's spirit or central fire—which would easily issue, at that time normally with fatal results, if the knee were wounded. Even this conception became degraded until at last it illustrated all the most contemptible potentialities of human nature; and we find Juvenal protesting against the way in which the Romans would plaster the knees of the gods with notes-of-hand, the actual votive offering being conditional on the gods' benevolence! Among the Jews the "token" idea has a history that throws a rich light on the stupidities of Sabbatarianism: wishing to travel on the Sabbath for a distance greater than a Sabbath day's journey from their homes, they would ingeniously take their homes with them in "token", by carrying a small larder!

A shared experience, usually of course the shared meal, intensified, if that were possible, the mutual obligations of host and guest. The sacred fire as the fuel of the larder figures in all those primitive marriage-rites that consist of a meal shared by the bride and bridegroom in synthesising the new home. It was present in the wine that was poured out in libation by plenipotentiaries who had just concluded an armistice or treaty. The Caste system among the Hindus is perhaps the strongest expression of the significance of the shared meal, but it is not without a significance in the literature of the European churches. It was a mingling of fuel, just as men have mingled their blood in rites of brotherhood by adoption, and here we may note that among the Romans the assumption by a pair of youths of the toga virilis before the same hearth bound them in amity for ever.

§ 73.

It was from the central fire in the human body that Plato and Galen derived the association of Heat with the colour of Blood. And here, as also in tears and sweat—but there without the essential redness—we have Fire, Water and Salt together. Plato says that in the body "the red predominates, as its nature consists of fire combined with moist mud. Hence also the colour of that which flows about the body is just what it seems; and it is also called Blood, being the nurturing principle of the flesh and of the whole body". Plato therefore conceived that the Creator implanted in the body "a hot moisture which in summer perspires and gives forth a cooling dew, and in winter gently keeps out the external cold by its own heat".

The sacredness of this central fire in Plato, whose own beloved master had quenched his with a draught of the "cold" hemlock, has been twisted by unscrupulous theologians into a divine injunction against suicide, and fathered on to "Christian" religions which purport to teach the philosophy of Jesus; whose example and teaching were consistently and entirely in opposition to the principle of "holding one's own life dear". It is so also they have twisted the superstition of the barbarous backwoods into "the divine law against the witch" and the villager's prurient nastiness into the Holy Ordinance of Marriage. They have omitted to notice the Divine Law against twins, under cover of which some African tribes savage an unlucky mother, and the Divine Law against ocean traffic between countries which God in His creative wisdom made separate. Thus, then, "the Almighty's canon 'gainst self-slaughter", piously invoked by Shakespeare through the mouths both of Hamlet and of Imogen, refers to Plato and to those older Egyptioid systems that saw in the body a sacred hearth, the tabooed temple of a holy spirit. Some of the terrible results of this teaching will be discussed later.

The radiation from the central fire in the body was recognised by Plato as permeating the whole mass; but it had also a focus or central hearth, and this was not in the intestines but in the liver. "In any animal in the World", he writes, "those internal parts are hottest which surround the veins and blood, just as if they contained a fountain of Fire; and this Heat we have compared with a bow-net, extending through the midst of the body and woven wholly of Fire". Such a fountain was located by Aristotle also in the liver, a point in which Plato and

his pupil depart from the old Chinese conception in which the worship of the Red Bird God linked Mars, the Sun, Fire and Summer, not with the liver but with the heart. In ancient Egypt, though in derivation from earlier sacramental cannibalism the bowel and liver were honoured, it was the heart that was the inner hearth and the inner fountain. It was, however, the liver of Prometheus on which the cleanly vulture fed, evidently in token of the crime which his punishment thus fitted; and Paracelsus, following the Greeks once more, asserts that "the origin of the blood is in the liver, and hence it flows forth through the veins over the whole body and is coagulated into flesh".

§ 74.

This particular aspect of bodily existence is familiar to readers of Shakespeare, of Greene, and of their contemporaries and predecessors back to Chaucer. It still plays an enormous rôle in the vocabulary of our language of health, happiness and melancholy. As generally believed in England, it was very fully stated by Bartholomew:

> "A spirit is a certain substance, subtle and airy, that stirreth and exciteth the virtues of the body to their doings and works. It is a subtle body, by the strength of heat gendered, and in man's body giving life by the veins of the body, and by the veins and pulses giveth to beasts breath, life and pulses, and working, wilful moving and wit, by means of sinews (i.e., nerves) and muscles to bodies that have souls. Physicians say that this spirit is gendered in this manner wise: whiles, by heat working in the blood, in the liver is caused strong boiling and seething, and thereof cometh a smoake, the which is pured and made subtle of the veins of the liver. And turneth into a

subtle spiritual substance and airly kind, and that is called the natural spirit. For kindly by the might thereof it makes the blood subtle. And by the lightness thereof it moveth the blood and sendeth it about into all the limbs. And this same spirit turneth to heartward by certain veins. And there by moving and smiting together of the parts of the heart, the spirit is more pured and turned into a more subtle kind. And then it is called of physicians the vital spirit: because that from the heart, by the wosen (i.e., arteries) and veins and small ways, it spreadeth itself into all the limbs of the body and increaseth the virtues spiritual and ruleth and keepeth the works thereof. For out of a den (i.e., cell) on the left side of the heart cometh a vein and in his moving is departed into two branches; the one thereof goeth downwards and spreadeth into many boughs and sprays, by means of which the vital spirit is brought to give the life to all the nether limbs of the body. . . . And so the vital spirit is spread into all the body and worketh in the veins the pulses of life. . . . The same spirit piercing and passing forth to the dens of the brain, is there more directed and made subtle, and is changed into the animal spirit, which is more subtle than the other. . . . Thus one and the same spirit is named by divers names. For by working in the liver, it is called the natural spirit, in the heart the vital spirit, and in the head the animal spirit. We may not believe that this spirit is Man's reasonable soul, but, more soothly, as saith Augustine, the car thereof and proper instrument. . . . If these spirits be impaired, the accord of the body and soul is resolved . . . as it is seen in them that be amazed, and madmen and frantic".

A concordance of Shakespeare on these spirits—which would be an immense volume—would show that courage, strength, vigour and happiness postulate a very lively upthrust, as where Romeo is "lifted above the ground", and this is due as always to their fire or heat. On the other hand, when Hero "sank down", it is because her

spirits were "smothered up". (Later, young ladies suffered from "vapours".) This is a reminder that the metaphor of "fanning up one's courage" goes back to Theopompus. To Bacon's best speculation on these spirits we must return, but his fundamental feeling is very similar. Of the effects of terror, he says: "In fear, the heat draweth inward toward the heart"—a synthesis of the bodily spirits similar to that of the threatened state, so that the individual might feel "collected". He recommends a digestive beverage after fatty food by saying: "To keep the oil from frying in the stomach, you must drink a good draught of mild beer after it".

By another scientific contemporary of Shakespeare we are made to understand that just as one exhalation from the "spirits" may issue from the nostrils and mouth, another is emitted from the eyes. This is from Porta, as translated by Reginald Scot:

> "This fascination, tho it begin by touching or breathing is alwaies accomplished and finished by the eie, as an extermination or expulsion of the spirits thro the eies, approching to the hart of the bewitched and infecting the same. Wherby it commeth to pass that a child or a young man endued with a cleare whole subtill and sweet bloud yieldeth the like spirits, breath and vapors springing from the purer bloud of the hart. And the lightest and finest spirits, ascending into the highest parts of the head, doo fall into the eies, and so are from thence sent foorth, as being of all other parts of the bodie the most cleare and fullest of veines and pores, and with the verie spirit or vapor proceeding thence is conveied out as it were by beames and streames a certeine fierie force; whereof he that beholdeth sore eies shall have good experience. For the poison of disease in the eie infecteth the aire next unto it and the same proceedeth further, carrieng with it the vapor and infection of the corrupted bloud: with the

> contagion whereof the eies of the beholders are most apt to be infected. By this same meanes it is thought that the cockatrice depriveth the life, and the woolfe taketh awaie the voice, of such as they suddenlie meete withall and behold".

The contemporary view of sight and of blindness had indeed descended without interruption or seriously successful challenge from the time depicted in the *Old Testament,* and the contemporary translations of the Hebrew literature were to stamp much of it into stereotype. For to the Egyptian and the Hebrew, blindness was the darkening of the windows, shutting the light *in.* In the *Prophecy of Zechariah,* that is the evident intention where the right eye of the palsied shepherd is darkened. In *Ecclesiastes,* the animal spirits, "they that look out at the windows", are darkened. In our own language, mine that it is of old lore, the eyes may still "light up" with "high spirits" or become "dull" with "low", as "the heart sinks". We have spoken already of these "sight-rays", however, and here would pause only to record one view extraordinarily striking in its isolation and contrariety: from one of the sayings of Jesus—and it is recorded in two gospels—it seems clear that He regarded the darkening of the windows in blindness as shutting the light not in but *out.*

§ 75.

In all these illustrations, it is evident that the Fire is connected with heat. Yet the twin connection with the cold energy of living water was not forgotten by Plato. Even the African savage had seen that. So the Mexican with the instinct to sympathetic magic, though

he knew little of the principle of Anaxagoras, made the blood-sacrifice in order to bring down that higher compound of Water and Energy, the Rain. The Aztec even conceived that there was a proportion in quantity between the sacrifice and the benefit. The kindly Maya employed, however, the blood of wild animals, and, by a further kindred extension in thought, even this often only in "token", what was actually burnt being modelled in resin, the blood of the tree. Thus also Jeremiah described the bounty of God as a fountain of living water which his countrymen were neglecting for the stagnant contents of their chipped cisterns, and Ezekiel saw it as a River flowing from the Holy Place into the World. So too in Isaiah, and in Keats, the informing Word of Immortal Truth is likened to an endless fountain pouring down to us from the brink of Heaven. So in the philosophy of Jesus the microcosmic Word in Man responds, a well of living water, springing upwards, informed by the energy implanted by the source towards which it turns.

Still, it was essential for blood to be warm and, if the warmth went, the life was gone. So Plato for his part combined Water and Energy in the phrase "hot moisture". Blood was a mysterious illustration of a mystical compounding of two opposites. In itself, it became an agent of compounding, of growth and of cohesion. The natural heat and radical moisture provided "the living bands of union uniting Soul and Body".

And now this union became so much taken for granted that the two things by later thinkers were again analytically separated, the moisture or "mercury" being the principle of circulation, while the "sulphur" or heat remained central, the principle that made the water live.

The Augustan poets, we find, give Mercury golden locks, and the wings of his sandals are gold also. Can that be sheer accident? We should add perhaps that theologians held that the energy of bodily circulation might also be evil, and that monster of selfishness, Augustine, assigns for the abode of the Devil the evil heart of the impious Man-microcosm.

§ 76.

As the heavens receded, and the Earth was distinguished from the World, the Earth also became a microcosm—almost, indeed, a mammal: for at one time it was thought that water came out of it as milk is made. It had hearths also. Paracelsus says that the Archeus of the Earth rules and graduates the Ætnean and mineral fire in mountains in much the same way as the alchemist controls his furnace. It was motion within the Earth that drove up the spirits. Even in Shakespeare, Hotspur speaks sardonically of the Earth's "colic". Its lava was the gross blood of the central fire. The knowledge or supposition of this central fire in the Earth must naturally go back to the first observations of volcanic eruptions made by those who believed that the Earth was round. It was sufficiently dissimilar to the Nous of the World, but naturally so, for it was earthy. In the first century B.C., we find this earthy fire assumed as an axiom in a very pretty argument about the unknown source of the waters of the Nile. It was generally held that they came through from the Antipodes. This could not be true, said Diodorus Siculus, for, if so, they would be sterilised, whereas on the contrary they bred mice and other vermin. This point was acclaimed as unanswerable, for this *sort*

of generation was not doubted until the end of the seventeenth century A.D., when Hooke published the results of his microscopy. From Pliny, who mentions that caterpillars were generated by the dew, and Plutarch who tells of a bird, native to Persia, which was made of Air and Dew alone, to Shakespeare's Hamlet, who speaks of "a god kissing carrion"—a reminder that Beelzebub was Lord of Flies because he created them—and even to Bacon, spontaneous generation was implicitly believed, the idea of "seeds of fire" being another of those ideas which are not only Homeric but indeed as old as mankind. Only lately have we learned why fish appear in ornamental lakes and basins. They come from spawn, transported on the feet of birds as bees carry pollen. And after all, are they not seeds of fire? On the death of Cleomenes, the philosophers satisfied the Alexandrians of the harmlessness of a certain portent by saying "As oxen breed bees, putrefying horses breed wasps, and beetles rise from the carcasses of dead asses, so the humours and juices of the marrow of a man's body, coagulating, produce serpents". Being venomous, these would be cold, and this may have explained in Plutarch's eyes on the basis of Like to Like, why the Psylli could tame serpents and cure the bitten by sucking their wounds, for the Psylli (in Herodotus) went to war with the hot south wind and were exterminated. Paracelsus tells us that animals proceed from the putrefaction of herbs, and warns us that all life produced from putrefaction is venomous. He speaks also of "animals made by art in the glass". Nor must we forget that monsters are likewise generated in the air, from the droppings of the stars—"for a sperm falls from the stars".

An empirical sterilisation was old as a precautionary measure of health, for the venom of stagnant water might be removed by the application of fire. Here we recall the horn of the Unicorn, the cleansing of the Lernean marsh by Hercules, and the lump of rock-sulphur that a modern Odysseus will put in his Argus's drinking-water. Cyrus carried huge supplies of boiled water on his military expeditions. This was an attraction by similitude of substance, the fire beneath the cauldron abstracting the "fire that quickens Nilus' slime", as Shakespeare's Antony called it. The sense that it was a fire impure was in keeping with other notions about the central fires of things. The impurity of terrestrial fire has been discussed already in § 12. Virgil considers even torch-light, the light from the tree, unthinkable as applied to the service of Jove, and as for the fire of volcanic eruptions, the impure soul of the Earth, that was gross. To the Roman mind, it was because the cold ash it left behind was so dense and heavy that it made the very finest water-resisting cement. In the human body, the purest soul, strive as it might after the limit set by Heracleitos, had proportions of Air and of Wind in it; the spirits, in any event, contained also Earth and Water. The use of Earth among Elizabethan writers in the sense of brutality and baseness should not have baulked their commentators : it is very common in Shakespeare, where Air and Fire are employed in a similar way to indicate the finer emotions.

§ 77.

And now the human body and the earth, being types or models of the World in virtue of their central fires, must also closely imitate the World in all other respects.

But what, then, was the central fire of the World? In the celestial atlas of the Mexicans it was the zenith itself, governed by Xiuhtecutli, the fire-god and house-god, equipoised among the cross-bars of the compass sign. They were well aware of the earth's own hot core; that was governed by a plutonic god, Chantico. They did not confuse the two; rather they opposed them. So also the Egyptians called the zenith the heart of the Sky. Our nearer intellectual ancestors, however, long remained geocentric. The central fire of their World was not that of Philolaus or of Aristarchus who saw it in the Sun; it was concentric with the central fire of the Earth. This was taught by Plato, hence by Aristotle, and therefore by medieval orthodoxy, the Roman Church burning Giordano Bruno for maintaining the contrary. The concentric nature of the spheres of the World was generally affirmed until after the Renaissance, Descartes, as a submissive churchman, when he heard of the persecution of Galileo, dropping the idea of rotation about the Sun as if it were a hot brick. Indeed, it was far more dangerous. When Shakespeare makes Cressida speak of "the very centre of the Earth, drawing all things to it", it is as the Aristotelian Centre, not as a local centre of gravitation.

§ 78.

Plato's system of concentric spheres, however, seems to have become generally subject to a certain gentle and discreet modification. This happened later than Dante, though it was anticipated in the earlier cosmology of Hildegarde who retained a spherical form for the earth, but adopted oval forms for the outer skins of the World. For since the World was animal—a Platonic teaching—

and its outer cover the acme of smoothness, since it lay in a firmament or nest of pleasant warmth which irradiated and nurtured it, thus completing the hatching which its premature expulsion from the womb of Chaos had necessitated, men's minds harked back to ideas about the "seeds of things" as used in Anaxagoras and Empedocles, or in Virgil and Lucretius. They thus tended to go further back still, even to Egypt, and adopt the shape of the sleeping infant, the incubating egg.

This was not retrogression, for there was no notion of a globe in the early Egyptian cosmogony. It was spiral progress. The early Egyptian saw his flat, hill-bounded country lying beneath the yearning underside of the sky-goddess who supported herself on her hands and feet. The daily motion of the Sun began with birth and ended with swallowing. The egg that enclosed the whole was derivative from the egg of the Moon and the egg of the Sun. As before we give the Moon priority, since we find the use of eggs in worship connected with Resurrection. In the mysteries of Osiris at Denderah and elsewhere the paste of earth and spice and myrrh that was pressed into the golden mould of the body of the god was first made in the form of the Egg and in this form it was worshipped. In the worship of Isis the Egg was broken. The paste egg of the worship of Eastre, the Anglo-Saxon Persephone, the goddess restored in Spring, is still with us, and her day is still dependent on the date of the Spring Moon.

When the Egyptian adored the coming of the Spring Moon, which in every sense meant life to him, Osiris was the power who through Thoth, his Word or Glory, brought down the Nile-flood, and Isis was the generative faculty.

When Sun-worship came, the Sun was the celestial counterpart of the egg that the Beetle, *scarabæus sacer,* transported by pushing it along in front of him rolled up in a globe of dung: the archetype of the celestial treasure that the alchemist was to find in nitre.

Finally, of all the manifold spirits and souls that inhabited the Egyptian's body, each a necessary balsam against its decay, the spirit-soul alone was universally immortal. The tomb was its egg-shell. In the resurrection, "I rise up out of the Egg in the Hidden Land", but the resurrection also identifies the spirit-soul with the Creator, the Cosmic Soul, the only One. In some such way as this must have arisen, in Egypt, the creation myth of the Cosmic Egg: and the myths of Egypt were to a large extent the matrix of Europe.

So in Augustan days we find a Roman divination by sympathetic magic, which consisted in placing labelled eggs on the fire. Magically, the man thus became an egg. But Man was a microcosm. Hence all the microcosms were eggs. Thus the Universe became again the great World-Egg, having at its periphery the serene warmth of the immortal nest and containing within itself the varying warmth of struggling and dependent life. It was in an unconscious admission that their ideas about the Cosmos were influenced by their ideas of the small model that they called it now the *Macro* or *Mega* cosm.

The converse influence was enormous, though it was not in every case reduced to its final absurdity. The microcosm was often allotted inner planets, meteors, trees, vapour-cycles and intelligent inhabitants. Some alchemist writers provide not only a population but also a complete astronomical system, both in the human body

—wherein Paracelsus, a great admirer of the Magi, explained what we now call pre-natal influences as "the strong direction of the interior stars" of the mother—and in the earth.

§ 79.

As to the gnomes, Agricola, generally sceptical of the supernatural, was so far of his time as to write in his *De Re Metallica*, of "those pernicious mining pests, the fierce-looking demons". But there were also a kindlier sort, and in his *De Animantibus Subterraneis* we read :

> "Then there are the gentle kind which the Germans as well as the Greeks call *cobalos*, because they mimic men. They appear to laugh with glee and pretend to do much, but really do nothing. They are called little miners, because of their dwarfish stature, which is about two feet. They are venerable-looking and are clothed like miners in a filleted garment with a leather apron about their loins. This kind does not often trouble the miners, but they idle about in the shafts and tunnels and really do nothing, although they pretend to be busy in all kinds of labour, sometimes digging ore, and sometimes putting into buckets that which has been dug. Sometimes they throw pebbles at the workmen, but they rarely injure them unless the workmen first ridicule or curse them. They are not very dissimilar from Goblins, which occasionally appear to men when they go to or from their day's work, or when they attend their cattle. Because they generally appear benign to men, the Germans call them *guteli*. Those called *trulli*, which take the form of women as well as men, actually enter the service of some people, especially the Suions. The mining gnomes are especially active in the workings where metal has already been found, or where there are hopes of discovering it, and because of this they do not discourage the miners, but on the contrary urge them and cause them to labour more vigorously".

President Hoover, in his wonderful edition of the *De Re Metallica,* quotes this and makes the following comment:

> "The German miners were not alone in such beliefs, for miners generally accepted them—even to-day the faith in "knockers" has not entirely disappeared from Cornwall. Neither the sea nor the forest so lends itself to the substantiation of the supernatural as does the mine. The dead darkness, in which the miners' lamps serve only to distort every shape, the uncanny noises of restless rocks whose support has been undermined, the approach of danger and death without warning, the sudden vanishing or discovery of good fortune, all yield a thousand corroborations to minds long steeped in ignorance and prepared for the miraculous through religious teaching."

Even in the human body, the spirits became individual and anthropomorphic, a conceit greatly relished by Cyrano de Bergerac, and also employed quite definitely —though it may be only as a poetic device—by Shakespeare, as where he describes the communication of alarm to the brain:

> They, mustering to the quiet cabinet
> Where their dear governess and lady lies,
> Do tell her she is dreadfully beset
> And fright her with confusion of their cries.

The balance of probability is on the side of literalism; it was the only explanation that availed to explain the noises in the ears common in circumstances of turbulent emotion. Moreover the opponents of this conception offered no good alternative explanation of the operations of nature: "they are put off by the names of virtues, and natures, and actions, and passions, and other such logical words". So the spirit concept held sway until the time

of Harvey, who, in what seems a very dull and unimaginative fashion, "buried" it—what an army of unconstructive undertakers there was at this time!—and it remained "buried" until, like so many of these old theories that clowns have despised, it was resurrected under a new name to a position of authority and permanence. We speak now, not of "spirits", but of hormones, that is messengers, of phagocytes, that is venom-eaters. Even Harvey, who introduced to England the European discovery of the circulation of the blood—though he did not understand it—had to admit "signal powers of acting and effecting".

§ 80.

The earth itself was peculiarly susceptible to the new microcosmic allegory. Its crust was the egg-shell. It was well-known that it was peopled by gnomes. Paracelsus did not question it. It was unquestionable. Man, being solid, lived in a subtle atmosphere. The gnomes, being subtle, lived in an atmosphere of Earth. Boyle was not quite so sure, but Boyle was freeing himself from the old trammels and was therefore free equally from what were regarded as their logical corollaries. He made a note to enquire into the matter. What prejudiced the credibility of the conclusion was the belief that the earth contained in any event the unpurified souls of the dead, undergoing probation. There is a scene in *The Old Wives' Tale* where one of a chatting group suddenly disappears into the ground: one of the survivors is made to remark, "Well, good-bye, Jack", and the conversation proceeds without further interruption. When there is more leisure in the action of the play, it is explained that Jack was

dead, but had returned to carry out a debt of good nature.

Sedimentary deposits were veins of minerals that had grown from the Water into the Earth. Perhaps an early etymological muddle of the words mineral and metal helped to create the legend that these were geocosmic trees, the resin of which was "sulphur" and the fruits in various states of ripeness, the metals. As stars were "structures of the heaven", trees "structures of the earth", so were minerals "structures of the water". The idea is latent in Augustan literature again, where we often find stones as "bones of the earth". The idea is analysed more fully in the next chapter, and here we need only remark that the perfect fruit was "gold". "The gold is nourished in its tree", says Paracelsus, "as a cow in its pastures or an Epicurean in his cookshop".

§ 81.

The alchemist's furnace also was a microcosm. So was the alembic; sometimes it is called "the glass egg" or the "philosophical egg" and the chemist's retort has still this shape. One development was the flask, the temporary flattening of the flask's base being soon discarded except for work carried on at ordinary atmospheric temperatures. For the fiery firmament (of which the central fire was but the emanation, or word, or glory, or shekinah) the alchemist substituted Azoth or Alcazoth, the philosopher's fire, which, as we have seen, might be any one of ten or a dozen standard temperatures obtained with neat empiricism in some bell or other domed affair that would suggest the Egg. The arrangement for distillation with reflux is described over and over. The experimental material first, as Virgil puts it, "exhaled

every vicious quality under the influence of fire" and then suffered "dissolution into the elements". First arose the "water" or "phlegma" or "spirit" or "mercury"; then came the "fire" or "sulphur" or "calidum innatum", the inborn heat. Condensable vapours—and they conceived of no others—returned upon the "caput mortuum" or "ash" or "salt" or "calx" or "glass" or "vitriol" or "earth" that remained at the base, digesting it towards a new existence as a more glorious body. When the furnace enclosed the egg, this condensation took place, not on the warm roof, but in a middle region; and this corresponded with the Cloud Level of the Cosmos, the cooler plane of condensation where rode the planets. Thus, then, was distilled a "rain," as some of the alchemists described it, or, in the words of Raymond Lully, "a most subtil spirit, which, being first lifted up on high, is then turned into the similitude of sweat", this description clearly referring to a distillation where the fire was applied at the base alone.

§ 82.

The Fire and Water, the Natural Heat and Radical Moisture, of man's body were susceptible of similar treatment. Poultices, particularly hot powders, sliced-open pigeons' bodies—pigeons were hot little creatures—or mustard baths, all applied to the feet "to draw out the fever", pointed towards the use of a complete alembic or firmament surrounding the patient. This led to a rediscovery of one of the luxuries of the older era. In his *Furni Novi Philosophici,* Glauber designs a bath-cabinet, a heated box, which he calls "a wooden ark to be used as a dry bath for the purpose of provoking sweat and encouraging the lightness of the spirits". The idea

had been symbolised already in ghastly fashion by Gilles de Retz in his castle on the Loire who had sought to renovate his central fire by bathing in the blood of infants. A sardonic justice substituted the firmament of a fire more corrosive when he was burned at the stake. Perhaps one of the earliest accounts of a rudimentary Turkish bath is found in Herodotus, where he describes how the Scyths would intoxicate themselves with the fumes of hemp. He himself mentions its similarity to the vapour-baths of the Greeks.

§ 83.

Finally, the microcosmic concept was applied to the experimental substance, the metal or lump of ore itself. "There is another firmament in this place", says Paracelsus, "namely, the matter contained in the glass". There was also a central fire hidden in the stone. Glancing back along the rings of the spiral, we find that this very conception had in earlier days begotten a myth of fire-origin. It was narrated in *Shahnama,* the great poem of Firdousi that became the national epic of the Persian people. There Hushenk, the giant-killer, hurled a tremendous stone at a monstrous dragon. His aim was not too good, and the stone broke against a rock. "Light shone from the dark stone, the heart of the rock flashed out in glory, and fire was seen for the first time in the World". Among the Hebrews we find stories, inherently no less credible, of rocks that were sources of water. Among the Greeks such a rock was a metamorphosis of Niobe, bereft of her twelve beautiful children. Among the Romans, since, as Virgil said, Jove was in all things, we naturally find a Jupiter Lapis whose special rôle it

was to hallow compacts and agreements; and indeed Laban and Jacob would have understood that. The ancients thought they knew of three stones possessing souls particularly willing or eager to manifest themselves. There was the sarcophagus, which would in forty days consume anything placed within its central hollow. There were amber and the lodestone. Theophrastus says that "Amber also is a stone. It is dug out of the earth in Liguria. Like the lodestone, it has an attractive power". Sennert, a contemporary of Shakespeare and of Bacon, writes of amber: "When it is rubbed with a rag, its ghost goeth forth and draweth morsels of chaff or of dry sawdust inwards unto itself". About the same time, Porta was writing in his *Magic* that when the lodestone was ignited (on charcoal, however, as Boyle was to point out) its magnetic soul or ghost appeared as a momentary blue flame. Paracelsus had taught that the soul of this stone had the same power over disease as it had over steel or iron; in each case it drew forth the fiery spirit. Barnes fought gallantly for "fire-ghost" as a name for electricity.

§ 84.

We come thus to a conception, long foreshadowed it is true, but highly important in the development of chemical thought. When the body in the alembic gave off its soul and its spirits, it lost also its form and its coherence, the gift of Water and the gift of Fire. It was "mortified". It had lost something akin to that mysterious "life" or "balsam" which preserves the living organism from decay. Hence the cohesive principle, corresponding to the Unicorn or Nous or Soul of the Cosmos, lay either in the Soul or in the Spirits. But the claim of the condensable portion to the rôle was founded

only in the fact that it was the vehicle of the fire; it was a claim that was finally to give precedence to that of the fire itself.

§ 85.

This brings us to the final application of the microcosmic idea. Everything was a microcosm. Every substance was compounded of an outward rind and an inner excellence, an outward vesture and an inward soul, of outer form and inward body, of female yolk enveloping an active male principle, of unripened substance and an inward heat, of Water active with a principle of Life, of Isis and Osiris, of "mercury" and "sulphur". The outer heat matured and ripened the fire within. Why should God discriminate against minerals, the third part of the temple of His glory? Like animals and vegetables, they too had seeds and souls. They too might reach their highest maturity and be Gold.

This belief was not purely alchemical. Heracleitos had written "All parts of the Universe are filled with spirits and with demons". This is hardly exaggerated by Paracelsus where he says:

> "The air lives of itself and gives life to all other things. This life is a spiritual essence. It remains always living. It leaves the body separate and dead and returns to its source which is Chaos and the air of the higher or lower firmament. There are different kinds of spirits just as there are different kinds of bodies. There are celestial and infernal spirits, human and metallic, the spirits of salts, gems and marcasites, animal spirits, spirits of potables, of roots, of liquids, of flesh, blood, bones, etc. . . .
>
> "With regard to the death of Man, it is simply the end of his day's work, the taking away his air, the evanescence of his balsam, the extinction of his natural light".

He implies, however, that even the caput mortuum receives new life when brought into the Air, and this was another of his attempts to explain changes of colour, for this, he said, was the assumption of the lovelier body of the after-life. Bacon writes: "In every tangible body there is a spirit, an entity thin and invisible, yet having place and dimension and real, a middle nature between flame—which is momentany—and air—which is permanent". The nature of these spirits, like that of Plato's Hot Moisture, is "a fine commixture of flame and an aerial substance", for they are "all, in some degree, more or less kindled and inflamed". The characteristic of plants, as distinguished from animals, was that this degree was low.

§ 86.

But what were Air and Flame? They were still steam in the inane and fire in the inane. He says that they are the representatives, among "the inferior order of pneumaticals" of the Mercury family of things and the Sulphur family of things. Harvey, writing of the contemporary medical schools with some amount of contempt, says that "They will have the more volatile portion to be the Band of Union", and we shall see that this was well exemplified by that fascinating ore which they could make themselves by the artificial union of rock-sulphur and metallic mercury. Still, they were dogged by a difficulty innate in their terminology. For if they put on one side the usual Platonesque view that the calx was the residue (or salt) of a metal that had already lost its form and cohesive principle, then—distilling a nodule of calx—they found that there issued a Fixed Air, the principle of cohesion or fixing in the

nodule. Thus from pyrolusite or red lead they would get the Fixed Air which Boyle was to regard as ponderable heat, and which we call oxygen.

§87.

On the other hand, distilling marble or limestone or other carbonaceous minerals, though indeed cohesion was lost when there issued that Fixed Air which we call carbon dioxide, yet clearly it seemed that Fire in this instance had entered into the resulting ash, or lime, and made it so live or quick that when it was quenched with water the water boiled. The mild soul of the ore had issued—for the Band of Union was gone—but a fiercer fire like the devil of the parable had entered in.

Thus we come to the conception that the "sulphur" in a body was twofold. It had an incombustible sulphur which it retained; but its Band of Union was a volatile sulphur, and this it lost. It was because Stephen Hales completed a research which Paracelsus had conceived and declined (for Hales was curious about the quantitative proportion in bodies of their Cohesive Principle) that he distilled, among other things, nitre; and found that the loss in weight due to the evolution of the Band of Union, which he collected in a bottle, was about one-eighth of the original mass. He then was the first to face this astonishing paradox: this Band of Union, to all appearance, was not Fire at all. It was an Air.

This was a novel thought which should fitly end a chapter of the History of Chemistry. The child who knows the Sun and is told of suns may perhaps experience a sensation such as these men felt, who knew Air and discovered that there were Airs.

§ 88.

But what then of cinnabar, the archetype and mnemonic of the older view? When Greek and Roman artificers burned it, the flames of its own sulphur—real sulphur this time—drove off the entire residue in a dark vapour that condensed and ran together in the strange liquid metal that was called Mercury. Here, for the ancient alchemist, was all matter: Fire and Water; Heaven and the Ocean. But Salt was lacking, and all things created by the hand of God were sealed with Three. So, therefore, from Geber, Morien, Arnold, Isaac and Paracelsus onward, we have the Theory of the Three Components, any two of which were bound by the third. Even in the behaviour of cinnabar, the universal necessity remained; cinnabar was indeed a beautiful illustration of their belief that salt itself was a mystical compound of Fire and Water. In the medieval salt works, where by boiling they "changed water into salt", did they not add beer and bullock's blood "to bring it down"? Moreover, here was a further conception: in fuels such as cinnabar, Fire was not only the agent of cohesion; like the balsam of the Mind of Man, it was the very matter of its Flame.

CHAPTER V.

THE SPIRIT IN PRISON.

This lapwing runs away with the shell on his head.
—*Shakespeare's Horatio.*

I was born with a caul.—Dickens (*David Copperfield*).

§ 89.

With the image of the Egg fresh in his mind, the reader will abandon the ecclesiastical misinterpretation of Peter's remark that the Spirit of Jesus, having been made free, preached to the spirits in prison. In Peter's day the metaphor was trite. "With what a husk I am now enveloped!" cries Lucilius in the second century B.C., using the word *folliculus* or seed-pod, and remarking that "All natural philosophers affirm that man is made of Soul and Body". The pyramid text of Teta, who reigned about 3300 B.C., contains the phrase "the empty case of Horus". In more recent times Paracelsus has written that "we are prisoned within a shell" and he remarks also that "the house is always dead, but the inhabitant lives". "Come, away!" says Shakespeare's Cleopatra of the body of Antony, "the case of that huge spirit now is cold". But why does Samson "grind in the prison-house"? Whence is this feeling of confinement? Does Shakespeare answer the question completely when he makes Hamlet say "I could be bounded in a nut-shell and count myself a king of infinite space, were it not that I have bad dreams"? Certainly there was an Egyptian

god in the Ninth Region of the soul's journey, "a holy god, who dwelled in his Egg" for ever and ever.

But we must return now to that other microcosm, the chemical substance: we have seen how by long-continued processes of analogy this also was conceived as consisting of "Soul" and "Body"; and just as in the fourth century B.C., a Hebrew writer conceived that the Spirit of Man was the Candle of the Lord illuminating all the inward parts of the Body, so the alchemist saw the emergent soul of a fuel in the matter of its flame. Anything whatsoever that burned possessed clearly a central soul which was a portion of the common inflammable principle. The general argument leading to this conclusion may be summarised as follows.

Because each of the four regional elements was constitutionally impure, it would nourish. So plants were nourished by water—their food being its impurities—or similarly by air, whereby odours also might feed the human body. This nourishing property was of especial interest in respect of fire. As we have seen, the external warmth of the nest influenced the central fire of the microcosm according to its intensity, the degrees of influence being a fecundation, a nourishing, then a ripening or maturation, then a putrefaction, then a fermentation, and then, with certain materials, a flame—which was "a high degree of fermentation". This was a direct irradiation and pertained to the activity of fire alone. But fire might also nourish in the additive conducive manner of the other three elements. Just as brine nourished crystals with Earth, mustard nourished the blood with Fire. Ignition or sterilisation took away the central fire; but, since a substance remained—even were

it called a salt or calx or vitriol—it was necessary to double the part of the contained fire: what had exhaled was "a volatile sulphur"; a "fixed" or "incombustible" sulphur survived. When, following the steamy "mercury", the volatile "sulphur" came off, there was a flame. Hence the central fire in fuels was the principle of inflammability. While this applied to all the microcosms, and was admirably typified by the burning of unseasoned wood, the metals offered a particular interest because they were apparently exceptional. It was deemed that, in metals, as in blood, moisture and fire ("mercury" and "sulphur") were associated in a particularly fixed, perfect and inextricable union. Yet the "volatile sulphur" was apparently driven out by an acid ash, and hence, when hydrogen was first prepared, it was regarded as the expulsion of the inflammable principle or "volatile sulphur" from the metal by the substitution of the "incombustible sulphur" or "vitriol". This notion was apparently confirmed in the late eighteenth century by fuel-investigators who used, not the alchemists' common denominator of "volatile sulphur", nor our present common denominator of "Heat of Combustion" or "Miles per gallon"; they conceived a palpable, substantial chemical "sulphur" which they preferred to call "phlogiston", and this conception was fated to endure just as long as the belief that the airy "sulphur", thinner and lighter than Air, that we call hydrogen, came *out* of metals, and that the fiery powder of quicklime *lost* "sulphur" as it became carbonated towards the neutral limestone from which fire had produced it.

Let us now go over the ground again with a little more attention to the general scenery.

§ 90.

The later European alchemists still held the theory of the Four Physical States, or Elements, largely as edited by Aristotle, though they themselves added glosses and occasionally passed over the boundary into caricature. Occasionally, too, they indulged in attempts to reconcile—though the object of that is difficult to understand—the Four Elements with the Three Components, playing with sacred numbers and a magic numerology that appears even puerile and has nothing of the attractiveness that attaches say to the tonal distances of Pythagoras. Their efforts recall the Vignette in the 79th chapter of the *Book of the Dead* described by Wallis Budge as "The deceased adoring three gods which represent the Four Sons of Horus". These reconciliations have no observable importance in the evolution of thought, and the reader is only muddled when the Chaos of one system masquerades in another as the Albumen of the World Egg. For the truth is that no striking success attended any of these mediating adventures, and in their multiplicity they often contradicted each other even in the same author, as when Paracelsus at one time identifies Chaos and Albumen—which is fairly good Egyptology—but at another explains that one is palpable and the other extremely subtle. It may be profitable, however, to attempt a composite of their views.

They identified the Hyle of Aristotle with the primeval chaos, which was invisible, impalpable, and of a slight green tint. It was also God, and the most vivid and accurate interpretation of this view was written in a brief flash of poetry by Marvell, whose lines triumphantly resist the usual fate of words too often quoted. It was

God in the Fires of Spring, reducing Creation to its original and final principle, "Annihilating all things made To a Green Thought in a Green Shade". If we have said little hitherto of green, we have not forgotten that it is the vesture of the triumphant Spring resurgence of the fire within the Earth, the chlamys of Persephone. The alchemists (and Boyle himself) sought to extract it from the emerald and from the celandine, and of the properties of the essence they obtained they told queer stories. This *primum ens* was also an *elixir vitæ*, a principle of renewal. On hens and on old women, it produced the logical results. We have said indeed that the Benu bird of Egypt was green, and we have remarked that from this bird the idea of the phœnix, the golden eagle, is commonly derived. What was the connection? Surely, to those old workers in gold leaf, that when the sunlight filtered through it, it was green!

This deduction is buttressed by a fact no less extraordinary: the ancient Egyptians tinted their faces less with ochre or with hæmatite than with malachite; and they knew that the metal produced, when this beautiful green ore was smelted, was copper, the gentle ghost and mimic of gold.

Two of the elements were active and two passive, but the category varied with the author. It was Nature that combined all the four elements into each substance or body, which then received its individual properties through the influence of some planet. As to the creation of the Four Elements themselves, one had the primacy; then the other three were created together. For the primacy of Fire, even if we limit our selection to one view per author, there is perhaps not even a bare majority of authors.

§ 91.

"The four fields thus set apart, there remained also four storehouses for keeping the four elements, namely, the Hot, the Cold, the Moist and the Dry". Some of the authors followed the lines exemplified by Bartholomew where he writes that a herb was "of Earth" and it was "cold and dry", that the ass was "a melancholy beast that is cold and dry, and is therefore kindly, heavy and slow, unlusty, dull, witless and forgetful", that the ape was "a witty beast that hath a dry brain". So each substance or body had an element-in-chief which was its mother, and also a complexion, "hot and dry", "hot and moist", "cold and moist", or "cold and dry". Paracelsus rightly belaboured the whole idea as monstrous nonsense and discarded on grounds crudely obvious and fallacious even the authentic doctrine that the elements themselves bore these complexions. Yet a century later, because of the direct access to Aristotle that was enjoyed by the educated (even in Chaucer's time) Bacon in one of his less felicitous moments is writing that the "spirits of men are hot and dry; the spirits of women are cold and moist".

§ 92.

After all, on things that mattered, these writers were orthodox. They went back not only to Aristotle but to Anaxagoras. Shakespeare refers to the Nous when he writes of "the prophetic Soul of the wide World, dreaming on things to come". Only the Fire of which this was the emanation was a pure element—the radiant light, the radiant heat. Anything else whatever was a composite of all the four elements. We may repeat, word for word,

what was said in § 53. Nothing was without Fire, save in an extreme indigence of nature; nothing was without Water that had Form, the gift of Water; nothing was without Air, for the surfaces of substances were worn and weathered into the Air; nothing was without Earth, for all things had weight. Any small sample of matter still sought alliance and union with a greater aggregate with which it had most in common. Clearly the impurity of the Four Elements as generally known was essential to this circulation. "All things are concealed in all", wrote Paracelsus, but in any particular substance only one of the four things present had the rôle of vehicle or transmitter of the remaining three. So any one element might be a Mother who "cherished" or "nourished"; any one element might be a receiver that "preyed". So Shakespeare mentions that the Air cherishes weeds, and Paracelsus is interested in his conclusion that Iron will lose matter (and, at any rate, its Form) to the attacks whether of Air, Water or Fire. Shakespeare is again perfectly in tune with current thought when he remarks in *Timon* that everything is a thief. Painting on a large scale in the Sonnets, he says that he has

> "seen the hungry Ocean gain
> Advantage on the kingdom of the Shore;
> And the firm Soil win of the watery Main,
> Increasing store with loss, and loss with store",

calling it "the interchange of state". So we can imagine an initiate impressed by the disappearance of a lump of camphor into the Air, by the drying-up of a crystal of washing soda, by the gradual growth of a puddle round a heap of salt; he would grasp these things by telling himself that the Air preyed on the camphor, taking away

all its four elements, that the Air preyed on the soda, taking away only its Water, and that the Air, as a vehicle of Water, nourished the salt by increasing its Water.

§ 93.

This preying and nourishing provided all the contemporary dramatists and poets with a pair of new catchwords. Inevitably, Dryden wrote:

"Pure Love, like pure Elements, will nourish least",

though indeed he overshot the mark, for Fire was the great exception; it was pure Fire that nursed all life and matter throughout the confines of the World.

§ 94.

It is a matter of some historical importance in other connections that plants were nourished by Water, which, it seemed clear, brought to them at least Earth and Fire. Primitive Man knew it, and the author of *Job* in the fifth century B.C. exquisitely describes how the old stock buds again "even at the very scent of Water". It is indeed difficult to know how far back this fact of science first burgeoned into poetry. In the Pyramid Text of Pepi, about 3200 B.C., we have this: "O Filler of the Lakes who makest to blossom the watercourses of the pure lake that comes forth from Osiris, thy winds are incense". In the fifteenth century of our own era it was laboriously proved by Nicholas of Cues or Cusa, a proof repeated with great éclat two centuries later by Van Helmont. The credit due to the alchemists lies in this, that they recognised in the Water a vehicle. So Evelyn writes, and how far he was indebted to his reading we do not know, that the rôle of the Water was "to dissolve and

qualify for insumption, something in the earth that is perhaps little more beside Sulphur".

§ 95.

The water had nourished the plants with *fire*. But Air was the element more commonly regarded as the vehicle of Fire—if only because lacking Fire it suffered a "version" into Water—and Evelyn also suggests investigations as to the best method of modifying the air in the vicinity of plants, so that the air might nourish them with fire. We have already seen in § 51 how air could supply hygroscopic bodies with water. It occurred to Bacon that air might also supply solid bodies with earth (a really genuine forecast of the mechanism of oxidation) and this by being received into their small pores, for "tangible bodies have no pleasure in the consort of air, but endeavour to subact it into a more dense body". Similarly, if bulbs sprouted when hanging in the air and gathered weight, "it is magnale naturæ; for it sheweth that air may be made so to be condensed as to be converted into a dense body; whereas the race and period of all things here above the earth is to extenuate and turn things to be more pneumatical and rare; and not to be retrograde, from pneumatical to that which is dense. It sheweth also that air can nourish; which is another matter of consequence". Shakespeare's Hamlet says that though he may have to live on promises, and chameleons on Air, "you cannot feed capons so". Bacon, however, reminds us that odours will nourish the human frame, and narrates the story of the dying Democritus, who kept himself alive for a few hours by smelling wine-soaked bread because he did not wish to inconvenience his

hostess. Wine in those days was commonly known as "a liquid sulphur". So, too, Cyrano in explanation of the lunar custom of living on odours writes: "You cannot have lived so long without having noticed that in your world cooks and pastry-cooks, who eat less than people of other occupations, are nevertheless fatter than they are. Whence is their fatness derived, unless it be from the smell of the food that perpetually surrounds them, penetrates their bodies and nourishes them?"

§ 96.

But in Sennert's category of "sulphurs" we find fats bracketed with rock-sulphur, carabe, resins and pitch. As with pollen (§ 29), it was "sulphur" again. That is a very good example, too, of how the fire radiated through the air cherished the central fire (or life) of the body. "The apple is a little Universe by itself whose core, which is warmer than the other parts, is a Sun, spreading about it the preserving heat of its globe; and the germ in the onion is the little Sun of that little World which heats and nourishes the vegetable salt of the mass". That is Cyrano, and the reference to the onion recalls the recent discovery that the voltage generated by the growth forces is, among the vegetables so far subjected to measurement, most constant in the onion. But this heat in itself was insufficient. Heat was so permeating and penetrant that it was as easily lost as gained. "Fire", said Plato, "is, of all classes of things, composed of the smallest parts, and hence it penetrates through water, earth and air, and their several compounds—and this to such an extent that nothing can retain it". Hence the very great importance to living things of the fire coming through the air to

replace this loss, for, says the *Philosophical Canon,* "when heat is extinguished in the vegetation or generation of anything, death suddenly invades the growing substance". That air was best which was properly "tempered", containing such proportion of fire as should efficiently overcome the natural enemy of corrosive fire, which yet had such affinity with air—moisture. From the other point of view, naturally the Water tempered the Fire. "The mid region of the Air has been arranged by Nature between Heaven and Earth, that the Sun and Stars should not burn up all terrestrial creatures". This interpretation of the quenching property of water need hardly be laboured. It was itself a form of energy and hence, among the neo-Epicureans, endowed the particles of water with the form of eels. As to its "tempering", even venom, or poison, had to be "tempered" before it could, with any hope of success, be offered to the victim.

§ 97.

We have examined at some length (§ 76) the old idea of the spontaneous generation of living things. Stories of the Virgin birth have gripped the imagination of Mankind since the early days of Egypt and of India. To this mode of creation, after his death, the disciples of Jesus attributed his origin. Though in none of his recorded sayings does he make this claim, though he differentiates in no way between the paternity of "My Father" and of "Our Father", this is yet a magnificent parable of the kindling of the intellectual and emotional life. If he disclaimed ties of human parenthood, it was probably to emphasise the divine parenthood which he shares with all those, equally equipped by divine parentage, whom he invited to imitate him. This inner

implantation by a divine spark from the outer Kingdom of Fire or Heaven—the region is indifferently so named by ancient writers—is a fitting start to its growth as described in the philosophy of Jesus, which of course should not be in any way confused with the doctrines of the religious organisations that have essayed to appropriate His Name. Here is the inner spark or leaven—a repudiation of the lifeless, unleavened bread of Judaism—developing itself under the genial influence of the heavenly radiance. Here is the inner well of living water, springing up under the influence of the heavenly rain unto everlasting life. The fire also is not only nourished but matured and brought to that ferment or leaven which is "like unto the kingdom of heaven". This simple poetical philosophy—and Plato said that poetry was the sunny balsam of the mind—has suffered iniquitous distortions at the hands of Judaistic and Roman "interpreters"; it is poles apart from the religious conception. On the one hand is the tragedy of canine worship, the grovelling "begging" of the dog to a higher being beyond his ken. On the other is the happy, questing adoration of the child—"of such is the kingdom of heaven"—not for a higher order of being, but for a kindly adult being of his own blood, the source and author of his own life, the father. "And here", says Paracelsus, "is the basis of all philosophy, where Man stands upright as a straight line looking up to Heaven". The religions that murdered Jesus, or, shall we say, executed Him for heresy, have for nineteen centuries sought also to sterilise his philosophy; yet the leaven has worked, for leaven must work, following the mathematician's eternal curve of growth, and in recent years we have watched its gradient rapidly

rising; the old bottles at last being rent, as his philosophy itself has rent the man-made veil of the temple separating God and Man. It is a philosophy that is sealed with the simplicity of genius and inspiration. It has never been surpassed.

The distinction between the development of the divine spark in the human animal as against the non-human is that Man may regulate his own growth. Among all the extravagances of the alchemists, this was never claimed for the experimental substance. The principle is stated by Al Iraki in the Muktasab: "Fire strengthens its like and weakens its opposite". A mild application of the outer fire, therefore, having first caused fecundation, proceeded to nourish and to ripen the fire implanted. An external heat too high, particularly when assisted by the vehicle of moisture, exercised an overwhelming attraction on the inner heat, the result being putrefaction. Thus Bacon, again in alignment with these less respectable philosophers, writes that "putrefaction is the work of the spirits of bodies" (the steams of their central fires) "which ever are unquiet to get forth and congregate with the Air, and to enjoy the sunbeams".

Will it be believed that one of his clerical biographers has made this playful sentence a reproach to him as indicating that at heart he was a spiritualist!

Such a heat, also, was "fermentation", for putrefaction, as we have seen, encouraged those forms of life which were thought at that time to be spontaneously generated. A yet more intense application of heat—and this meant dry heat—might produce flame. Hence Mayow affirms that "Flame is but a high degree of fermentation". But now "the principal spirits which", in

Bacon's words, "preserve the consistence of the body" were exhaled, and hence that volatile sulphur which was the principle of cohesion, or band of union, was also the principle of inflammability. If there were no flame, then the substance was poor in volatile sulphur, or this constituent was choked by the accompanying aqueous steams, as in green wood burned. In any event, the residue contained a "fixed sulphur", an explanation which happily explained the corrosive qualities of such bodies as quicklime and vitriol. The purer type of earthly fire had departed from the microcosm, but the grosser type remained, recalling the Element of Earth.

§ 98.

Another line of thought also led to the idea of an inflammable principle. When seeds are thrown on to the fire, says Evelyn, "their little souls exhale". The outer fire had evoked or educed the inner fire. At a time when fumes and forces were still in the same category, consider the effect of such an experience as this of Boyle's: A lump of amber on the window-sill was quiet and inactive until placed in the sunlight. Then, however, "sunbeams quickly put its parts into such an agitation as made it emit electrical effluvia and readily attract those light bodies that would not stir before". It "soon, but not immediately", lost its attractive properties when put in the shadow. Plato had attributed such phenomena to an actual movement of material particles; but then, his "soul" itself was constituted by material particles. According to Sennert, this uncanny activity was due to an excursion of the soul of the microcosm, induced by the outer fire. Moreover, did not wood itself behave in

a similar way, emitting fire whether after friction or after solarisation? At this point entered the old identification of wood with fire. And, if wood was fire, so were all fuels. "Flame come on stick" says the two-year old of the twentieth century, regarding a match: these earlier thinkers came also to that conclusion; but they followed on to the next step—that the flame came out of the stick. It was quite simply freed from its moisture and its salt into the Air.

§ 99.

A difficulty arose when the experimental substance, say a morsel of stone, yielded neither flame nor moisture. By some sport in nature, as it appeared to the alchemists, there was no volatile sulphur in flint. Nevertheless they regarded it as the foremost of the fire-making materials. Virgil speaks of the fire being "hidden" or "latent" in its veins. Shakespeare's Brutus taunts Cassius with carrying "anger as the flint bears fire,

"Who, much enforced, shows a hasty spark
"And straight is cold again".

Hooke, with his microscope, demonstrated the fallacy, but betrays the fact that he also accepts the idea of an inflammable principle. This resided, not in the flint, indeed, but in the steel. Later, we shall transcribe his explanation. First, we must try to re-create the philosophic background which made it credible.

§ 100.

When the alchemist heated his animal or vegetable product, it dried; that is, it gave off its phlegma or water or moisture or mercury or spirit. As the temperature

rose, decomposition set in and its soul, its fire, which was the matter of flame, issued. This was the volatile sulphur. The caput mortuum was an ash, or a glass, or a fixed salt. It contained "incombustible sulphur" or "fixed sulphur". If this were taken hot from the alembic into the air, it would often blaze violently, and thus "the incombustible sulphur in the centre of the alkaline salt, on exposure to the air, manifests itself both to the sight and touch". To use an analogy only partially complete, Jove, we may say, had received the divine spark of life, the soul or volatile sulphur, and Jove had savoured the mercury, the odours of the sacrifice; but the roasted flesh of the victim, covered with salt and spelt, remained to nourish the cruder necessities of the earthly worshipper and of the human priest.

§ 101.

The alchemist applied this reasoning also to the alluvial mineral. When the typical inflammable material, rock sulphur, was ignited, the volatile matter of flame disappeared, and "oil of sulphur" or "vitriol" remained. This was the incombustible or fixed sulphur. It corresponded to the ash or calx or salt. There was to be a differentiation later, when it was discovered that in some senses the calx-ash and the acid-ash were opposing poles. That was not yet. But later chemists were to call these "Alkali" and "Acid", each dependent on Water, and in their union producing what we *now* call a "salt". The heating properties of this vitriol were employed medicinally. It was to be taken in water in such proportions that its taste had "about the sharpness of vinegar", and it was used as a tonic beverage, as a preservative, as a febrifuge and as a mouthwash, making the teeth "like ivory".

It was to be made by burning sulphur under a glass bell or egg-shell, and it was pretended that ordinary mineral sulphur was not good enough for the purpose, being arsenical, and that "oil of sulphur" was not identical with the vitriol sold by knavish apothecaries. We find Richard Mead, a physician who according to Johnson's Boswell was very eminent in the middle of the eighteenth century, still prescribing for "diseases of the stomach and intestines", "Mynsicht's elixir of vitriol". Diderich, writing in 1710, calls it *Balsam sulphuris*. Under various proprietary names, pharmacists sell it still.

§ 102.

Similarly, the earth itself had two sulphurs. Fat or pinguid earth, which contained, as Evelyn thought at least, the saps of plants ready made for their use, was rich in an analogue of the volatile variety. Its crops were green luxuriant things. Choleric, or burnt, earth had a fixed sulphur and its fruits were spices and hot things in general. Red earths had always been thought choleric, as attested by the lard and ochre decoration of the savage or by the writings, for example, of Columella. Even in Evelyn's time, it was still "a vulgar notion" that sandy soil was choleric. Contributory to the old bracketing of heat and redness was an ancient association of gold with such soil, and another factor may have been the correspondence between sand and the caput mortuum of many mineral bodies. The direct association of sand with gold is at least older than Herodotus, who tells how Indian ants, bigger than foxes, were employed—trained, no doubt, by kindness—to burrow for gold in the desert.

§ 103.

Plutarch's description of an oil-field illustrates one natural occasion for the confusion of unctuosity with choler. Here we have in the geocosm the volatile sulphur or "fat" being emitted from the choleric earth, and the passage is quoted in full, except for a somewhat tantalising hiatus in the middle, because it is one of the finest historical documents in the history of fire and flame :

> "In Ecbatana, Alexander was much surprised at the sight of the place where fire issues in a continuous stream, like a spring of water, out of a cleft in the earth, and the stream of naphtha, which, not far from this spot, flows out so abundantly as to form a sort of lake. This naphtha, in other respects resembling bitumen, is so subject to take fire, that before it touches the flame it will kindle at the very light that surrounds it, and often inflame the intermediate air also. The barbarians, to show the power and nature of it, sprinkled the street that led to the king's lodgings with little drops of it, and when it was almost night, stood at the further end with torches, which being applied to the moistened places, the first at once taking fire, instantly, as quick as man could think of it, it caught from one end to another, in such a manner that the whole street was one continued flame. Among those who used to wait on the king and find occasion to amuse him when he annointed and washed himself, there was one Athenophanes, an Athenian, who desired him to make an experiment of the naphtha upon Stephanus, who stood by in the bathing-place, a youth with a ridiculously ugly face, whose talent was singing well. 'For', said he, 'if it take hold of him and is not put out, it must undeniably be allowed to be of the most invincible strength'. The youth, as it happened, readily consented to undergo the trial, and as soon as he was annointed and rubbed with it, his whole body broke out into such a flame, and was so seized by the fire, that Alexander was in the greatest perplexity and alarm for him, and not without reason; for nothing could

have prevented him being consumed by it, if by a good chance, there had not been people at hand with a great many vessels of water for the service of the bath, with all which they had much ado to extinguish the fire; and his body was so burned all over that he was not cured of it for a good while after. Thus it is not without some plausibility that they endeavour to reconcile the fable to truth, who say this was the drug in the tragedies with which Medea annointed the crown and veil which she gave to Creon's daughter. For neither the things themselves, nor the fire, could kindle of its own accord, but being prepared for it by the naphtha, they imperceptibly attracted and caught a flame which happened to be brought near them. For the rays and emanations of fire at a distance have no other effect upon some bodies than bare light and heat, but in others, where they meet with airy dryness, and also sufficient rich moisture, they collect themselves and soon kindle and create a transformation. The manner, however, of the production of naphtha admits of a diversity of opinion".

It is just here that the hiatus so tragically occurs. He resumes:

"Or whether this liquid substance that feeds the flame does not rather proceed from a soil that is unctuous and productive of fire as that of the province of Babylon is, where the ground is so very hot that oftentimes the grains of barley leap up and are thrown out, as if the violent inflammation had made the earth throb; and in the extreme heats the inhabitants are wont to sleep upon skins filled with water. Harpalus, who was left governor of this country, and was desirous to adorn the palace gardens and walks with Grecian plants, succeeded in raising all but ivy, which the earth would not bear, but constantly killed. For it is a plant that loves a cold (heavy and wet?) soil and the temper of this hot and fiery earth was improper for it. But such digressions as these the impatient reader will be more willing to pardon if they are kept within a moderate compass".

Philostratus explains the same thing more in accordance with our modern views when, of the same place, he writes: "The soil is drenched with pitch and is bitter to plant in; and the inhabitants are very short-lived, because the pitch in the water generally forms a sediment in their bowels". A local well, he says, contained pitch and oil, besides water, and a sample on standing would automatically settle out in three layers.

§ 104.

Metals were regarded by the alchemists as a particular kind of mineral, having its roots in the Ocean, that was nourished by the Ætnean fire of the Earth. Thus it was slowly ripened towards the state of being perfected as gold. They were made of "sulphur" and—with the not quite universal exception of gold—a certain proportion of "mercury". Subjected to an untempered heat, however, they lost the little mercury they had, and all their volatile sulphur, and so became a fixed calx or salt. The rusting of metals in damp air, therefore, and their corrosion by acids were operations similar in kind to calcination, and were attributable not to a "nourishing" —for they had not our quantitative chemical knowledge—but to improper treatment. The alchemists were fond of saying that such metals had been "torn up by the roots". (Here is a definite difference from Plato's teaching that what a metal lost in rusting was "earth", this being the Platonic expression of the fact that the density of a calx was less than the density of the metal.) The trouble evidently might be remedied by the application of the universal balsam. Like Paul's or Proteus', its superficial character varied with the problem. To preserve food,

Paracelsus employed fire in the form of essences; he "vulcanised" wood, ropes, nets and cloth with a preparation of sulphur and aqua fortis; for liquids the fiery balsam became a simple layer of olive oil. For metals, he employs not bitumen, as recommended by Pliny, but "fresh lard from a gelded sow"—the genuine Paracelsian touch!

But iron, fluxed in a certain way with "white arsenic", needed no rust-proof: it would never rust again. Our present knowledge of unstainable steel suggests that this "white arsenic" was chromium, a metal then "unknown".

§ 105.

Since the metals differed from each other only in degrees of maturation, then, though each had its specific sulphur or seed or germ, all were nourished by the same medium or yolk or "mercury" or first matter of metals. Probably nowhere is the detail of this theory more attractively stated than by the anonymous author of *The Philosopher's Stone*—a late writer, since he quotes Sendivogius, a pupil and plagiarist of Seton (who, himself a great thinker, quoted with due acknowledgments and sought authority always in the work of Paracelsus). He says:

> "The First Matter of Metals is a moist vapour, raised by the action of the central fire in the bowels of the earth, which, circulating through its pores, meets with the crude air, and is coagulated by it into an unctuous water, adhering to the earth, which serves it for a receptacle, where it is joined to a sulphur more or less pure, and a salt more or less fixing, which it attracts from the air, and, receiving a certain degree of coction from the central and solar heat,

is formed into stones and rocks, minerals and metals. These were all formed of the same moist vapour originally, but are thus varied from the different impregnations of the sperm, the quality of salt and sulphur with which it is fixed, and the purity of the earth which serves it for a matrix; for whatever portion of this moist vapour is hastily sublimed to the surface of the earth, taking along its impurities, is soon deprived of its purer parts by the constant action of heat, both solar and central, and the grosser parts, forming a mucilaginous substance, furnish the common matter of rocks and stones. But when this moist vapour is sublimed very slowly through a fine earth, not partaking of a sulphureous unctuosity, pebbles are formed; for the sperm of these beautiful, variegated stones, with marbles, alabasters, etc., separates this depurated vapour, both for their first formation and for their continual growth. Gems are in like manner formed of this moist vapour when it meets with pure salt water, with which it is fixed in a cold place. But if it is sublimed leisurely through places which are hot and pure, where the fatness of sulphur adheres to it, this vapour (which the philosophers call their Mercury) is joined to that fatness and becomes an unctuous matter, which coming afterwards to other places, cleansed by the afore-named vapours, where the earth is subtle, pure and moist, fills the pores of it, and so Sol or gold is made. But if the unctuous matter comes into places cold and impure, lead, or Saturn, is produced: if the earth be cold and pure, mixed with sulphur, the result is Venus or copper. The Moon, Silver, also is formed of this vapour, where it abounds in purity, but mixed with a lesser degree of sulphur and not sufficiently cocted. In tin, or Jupiter, as it is called, it abounds, but in less purity. In Mars, or iron, it is in a lesser proportion impure, and mixed with an adust sulphur. Hence it appears that the First Matter of Metals is one thing, and not many, homogeneous, but altered by the diversity of places and sulphurs with which it is combined".

§ 106.

Each writer of course re-wrote the theory in the light of his own prejudices. The individual variation in the description above is the omission of any categorical acknowledgment of selective planetary influences, together with the omission of the usual figure of the mineral tree, a figure which remains with us in the word "outcrop". The diversity of places is reconcilable, however, with the diversity of sulphurs. It is reconcilable also with the astrological basis, explicit in Paracelsus, who in some moods held that there were certain metals "not found among us" because the influences of the appropriate stars did not "reach our earth", and categorically accepted the orthodox astrological view of the seven metals and the seven planets. In other moods, it is true, he regards the whole astrological basis as obsolete.

§ 107.

Now Paracelsus says "That which smokes and evaporates over the fire is mercury, that which flames and is burnt is sulphur, and all ash is salt". Where was the volatile sulphur of metals? If we take the grave risk of making him answer from another context, "The resolution of a metal dissolved in the fire is not, as with resins, accompanied by flame. Mercury, therefore, holds the principal place therein". And elsewhere, "Each metal in the fire puts forth some peculiar sign, such as sparks, flames, brightness, etc. Iron sends forth limpid, clear sparks which rise to a height. As soon as these appear, unless the iron be at once removed from the fire, it will be burnt up like straw". But, of superior metals, "Minerals and metals which in the fire emit neither fume

nor flame—that is, neither smoke nor blaze—show an equal mixture of mercury and sulphur, and a fixity and perfection beyond all consistency". Why, then, did he think that in fire-kindling the sparks came from the flint? Were they not sufficiently limpid and clear? So it was Hooke who showed that they came from the steel, and because he lived just too late to talk dogmatically of "sulphur" and just too early to talk of phlogiston—a change of name due to a Christian Scientist who, by a foolish coincidence, was named Stahl—he says that the steel contains a combustible sulphureous body.

§ 108.

But let him speak for himself:

> "It is a very common experiment, by striking with a Flint against a Steel, to make certain fiery and shining Sparks to fly out from between those two compressing bodies. . . . The Spark appearing so bright in the falling is nothing else but a small piece of the Steel or Flint, but most commonly of the Steel, which by the violence of the stroke is at the same time severed and heated red-hot, and that sometimes to such a degree as to make it melt together into a small globule of steel; and sometimes also is that heat so very intense as further to melt it and vitrefy it;" (i.e., turn it into a calx) "but many times the heat is so gentle as to make the sliver only red-hot, which notwithstanding, falling upon the tinder (that is only a very curious small coal made of the small threads of Linnen burnt to coals and char'd) it easily sets it on fire. Nor will any part of this Hypothesis seem strange to him that considers, First, that either hammering, or filing, or otherwise violently rubbing of Steel, will presently make it so hot as to be able to burn one's fingers. Next, that the whole force of the stroke is exerted upon that small part where the Flint and Steel first touch: For the bodies,

being each of them so very hard, the puls cannot be far communicated, that is, the parts of each can yield but very little, and therefore the violence of the concussion will be exerted upon that piece of Steel which is cut off by the Flint. Thirdly, that the filings or small parts of Steel are very apt, as it were, to take fire, and are presently red-hot, that is there seems to be a very *combustible sulphureous* Body in Iron or Steel, which the Air very readily preys upon, as soon as the body is a little violently heated.

§ 109.

"And this is obvious in the filings of Steel or Iron cast through the flame of a Candle; for even by that sudden *transitus* of the small chips of Iron, they are heat red hot, and that *combustible sulphureous* Body is presently prey'd upon and devoured by the *aereal* incompassing *Menstruum,* whose office in this particular I have shewn in the Explication of Charcole. . . . So that, it seems, Iron does contain a very *combustible sulphureous* Body, which is, in all likelihood, one of the causes of this *Phaenomenon,* and which may perhaps be very much concerned in the business of its hardening and tempering. . . . So that, these things considered, we need not trouble ourselves to find out what kind of pores they are, both in the Flint and Steel, that contain the *Atoms of fire,* nor how those *Atoms* come to be hindered from running all out, when a dore or passage in their Pores is made by the concussion; nor need we trouble ourselves to examine by what Prometheus the Element of Fire comes to be fetcht down from above the Regions of the Air, in what Cells or Boxes it is kept, and what Epimetheus lets it go: Nor to consider what it is that causes so great a conflux of the atomical Particles of Fire, which are said to fly to a flaming Body, like Vultures or Eagles to a putrefying Carcase, and there to make a very great Pudder. Since we have nothing more difficult in this Hypothesis to conceive, first, as to the kindling of Tinder, then how a large Iron-bullet, let fall red or glowing hot upon a heap of Small-coal, should set fire to those

that are next to it first: Nor secondly, is this last more difficult to be explicated then that a Body, as Silver for instance, put into a weak *Menstruum,* as unrectified *Aqua fortis,* should, when it is put in a great heat, be there dissolved by it, and not before". (Small-coal was charcoal made from brushwood.)

§ 110.

Loth as he was to pay too much attention to ancient speculation, this great genius knew, and here accepted, the idea of the presence of "sulphur" in metals and in inflammable bodies. And he said *Iron* contained it. He was not referring to the well-known presence of carbon in *"cast-iron"* or *steel.* It was not he, however, feverishly jumping from one speculation or experiment to another entirely unrelated, but his patron, Boyle, who examined the effect upon iron of the "great arcanum" and medicine, that "incombustible fixed sulphur"—vitriol. The result of Boyle's experiment was apparently to release the "combustible sulphureous body", the volatile sulphur that Iron contained, for he was able to collect something which we now call "hydrogen". Hales would have called it the "Soul" or "Band of Union" of Iron.

Let us first premise that Boyle, who acutely felt his position as arbiter of the elegances of philosophy, freely employed the old nomenclature, referring, for example, to wine as "a real sulphur" and "a liquid sulphur". He writes of this experiment:

"Those sulphurs that chemists call metalline, being supposed by many to be of a much more fixed nature than common sulphur, and it being indeed probable enough, that in them good store of very minute particles are crowded together, I thought fit to try, whether a body, wherein a vulgar chemist would think the sulphur of a metal to be the main

ingredient, would afford in our vacuum a more vigorous or lasting flame than that of common sulphur. And, though I will not here trouble you with my particular scruples about the chemists' doctrine concerning metalline sulphurs, nor with the grounds on which I devised the following inflammable solution of Mars (for I do not now give it a more determinate name), which some chemists will not perhaps dislike; I shall here annex the ensuing transcript of the trial itself.

"Having provided a saline spirit, which by an uncommon way of preparation was made exceeding sharp and piercing, we put into a vial, capable of containing three or four ounces of water, a convenient quantity of filings of steel, which were not such as are commonly sold in shops to chemists and apothecaries (those being usually not free enough from rust), but such as I had a while before caused to be purposely filed off from a piece of good steel. This metalline powder being moistened in the vial with a little of the menstruum, was afterwards drenched with more; whereupon the mixture grew very hot, and belched up copious and stinking fumes; which, whether they consisted altogether of the volatile sulphur of the Mars, or of metalline steams participating of a sulphureous nature, and joined with the saline exhalations of the menstruum, is not necessary here to be discussed. But whencesoever this stinking smoke proceeded, so inflammable it was, that upon the approach of a lighted candle to it, it would readily enough take fire, and burn with a blueish, and somewhat greenish flame, at the mouth of the vial, for a good while together; and that, though with little light, yet with more strength, than one would easily suspect.

"This flaming vial therefore we conveyed into a receiver, which he, who used to manage the pump, affirmed that about six exsuctions would exhaust. And the receiver being well cemented on, upon the first suck the flame suddenly appeared four or five times as great as before; which I ascribed to this, that upon the withdrawing of the air, and consequently the weakening of its pressure, great

store of bubbles were produced in the menstruum, which breaking could not but supply the neck of the vial with store of inflammable steams, which, as we thought, took not fire without some noise; upon the second exsuction of the air, the flame blazed out as before, and so it likewise did upon the third exsuction, but after that it went out; nor could we re-kindle any fire by hastily removing the receiver; only we found that there remained such a disposition in the smoke to inflammability, that holding a lighted candle to it, a flame was quickly re-kindled".

§ 111.

It will be observed that Boyle did not commit himself, but such was the hold of the sulphur concept under its new name of Phlogiston that over a century later we find Priestley unquestioningly writing: "I have generally made inflammable air in the manner described by Mr. Cavendish in the Philosophical Transactions, from iron, zinc, or tin". Moreover Cavendish unconsciously produced evidence in support of the alchemical constitution of metals by his discovery that the amount of hydrogen "in" equal weights of the various metals varied. As Priestley put it, hydrogen either was phlogiston or was very rich in it.

§ 112.

Now the action of air and acid upon iron may be written as follows:

Air: $2Fe + 2O = 2FeO$ + a certain quantity of heat.

Acid: $2Fe + 2O(H_2) + 2SO_3 = 2(FeO.SO_3) + 2H_2$ + a certain quantity of heat.

The alchemists were right, therefore, in finding that the iron lost something, for it contributed to the evolution of heat; they had not realised, however, that at the same

time some of the air was "subacted into a denser medium". We may conclude quite definitely that if, as Hoefer asserts, Paracelsus had noticed the evolution of hydrogen, this would in no way have altered his views. Was not the element of Fire unthinkably lighter than the element of Air! Was not flame to fire as intelligence to the senses, something akin but immeasurably finer! Was not this exhalation the pre-flame substance! It is indeed a coincidence of the most extraordinary kind that the primal matter built up from the inchoate energy in outer space is Hydrogen. It is indeed a coincidence of the most extraordinary kind that where the ancients conceived an outer cosmic shell of thin "Fire" we have found an outer "stratosphere" whose tenuous outer limits are pure hydrogen.

But we speak nowadays, not of "central fire" or "sulphur" or "soul" or "Phlogiston"; we say "Calorific Value", "Heat of Combustion", "Miles per Gallon".

CHAPTER VI.

THE TWO HANDS OF NATURE.

For Heat and Cold are Nature's two hands.
—Bacon's *Sylva Sylvarum.*

§ 113.

To the Peripatetics, the antonym of heat was gravity, the cold associated with dense objects—"stone-cold", as we say—being corollary to this. When Aristotle's cosmogony began to lose credit, the instinctive belief in a positive cold became a respectable scientific theory. This positive cold was by no means connected with indigence and inertness, and it had some of the properties of radiance: thus it came to earth with the nitrous exhalations from the Cloud Level, and its effect on water was to expand it into ice as heat expanded it into steam. Thus Virgil notes that bronze water-jugs are burst by the cold, which also bridles the river and splits the rock. Bacon could correctly enunciate, and he first, a mechanical theory of heat and at the same time believe in this positive cold.

In Boyle's time, this idea of a positive cold was warmly contested by the Cartesians, who regarded cold as merely a relative defect of heat—the present position—but could not explain the production of freezing mixtures, the extreme cold produced for example when salt is dissolved in snow-water. When heat entered the chemist's equations, however, this new, measurable quantity solved them all. The idea of quantity in heat is still very useful in calculations. It has been of great assistance in the

study of chemical change, latent heat of physical change, specific heat, and so forth. Its use has spread also to other forms of energy. This quantity idea comes from investigators who conceived heat as a fluid, fulfilling the rôle in circulation which we now assign to oxygen—(no very wide straying, since oxygen itself was first dimly recognised as an influence or radiation from the Firmament). This conception held its ground until it was proved that the "caloric" from friction was inexhaustible save in respect of the work thus cashed; and that, in this exchange, heat had a constant equivalent in mechanical energy.

§ 114.

The idea of opposing poles appeared among the guiding principles of classical thought as a theory of limits determining an infinite series of intermediates. This principle has had a profound influence on subsequent speculation. We have noted it in the discussion on light, darkness and colours. In another field, Plutarch pointed out that between God and Man there must range by imperceptible steps an infinite number of spirits of intermediate power, and that symmetry required evil spirits also. Again, Evelyn writes, in *Terra*:

> "My Lord Bacon directs to the observation of the Rainbow, where its extremity seems to rest, as pointing to a more roscid and fertile Mould; but this, I conceive, may be very fallacious, it having two Horns, or Bases, which are ever opposite".

All this would have chimed well with the primitive conception of "cold", one of the oldest words of mankind, descriptive of a real, positive enemy, but, in the Platonic and Peripatetic systems, the pole opposing Fire was not

Cold, but Earth, density, gravity. Earth was also the pole opposing Fire in a second respect, for in its inertness it was antithetical to the fiery firmament rotating about it. Fire was the primum mobile. In any event, acceptance of whatsoever version of the hypothesis of the Four Elements excluded a positive "cold", since every substance contained only earth, water, air and fire. Inert and cold were privative adjectives. The Earth—"the cold, cold ground"—was primum frigidum, as it might also have been called primum immobile, but this did not endow, so much as deprive it.

§ 115.

The Epicureans of the Renaissance believed, however, in a positive cold, and their view gained in credibility as the antithesis betwen heat and gravity, together with the ancient geocentric cosmogony, became discredited. Some of them at once fell into the snare, that beset every system, of regarding Health as a simple Equilibrium. So we have in Beaumont and Fletcher:

> *Panthea:* Alas, sir, am I venom?
>
> *Arbaces:* I think thee to be in as equal a degree of Heat and Cold as Nature can make.

Among the alchemists there was, as we have seen, a tendency to regard Water as the "enemy" or "death" or "winter" of Fire, and therefore the primum frigidum. Hence, for example, to the Paracelsians, lead had a cold "spirit" (and was therefore an occasional cure for desperate cases of cancer), because the content of Fire (sulphur) was low, and the Moisture (mercury) content was high. But even this was originally derivative from the association of cold and density: "Is not lead a metal,

heavy, dull and slow?" asks Shakespeare's Armado. So also Shakespeare makes Mortimer say that the death of Percy turned the steel of his troops into lead, because their fire was gone. Paracelsus believed, too, that the true home of positive cold was in the middle region of the air (did not vapour condense there and fall as rain?) whence also came the influences which determined the proportions of metallic constituents. Like Virgil also, who tells us how the cool influences radiating from the Evening Star temper the hot air, he suspected that cold actually descended as an exhalation from the planets; and this was another pregnant concept, for these planetary exhalations acting upon dung begot nitre (a body cold to the tongue) which had a quick spirit and by some was identified in its turn with the Primum Frigidum. Thus he explained the cold which comes of dissolving substances in water by saying that "whatsoever is dissolved in fire, and by its heat, has in itself sweetness and cold, but not fire". And here is the idea of the two hands of what he calls "Ares" (Empedocles' Strife) "the occult dispenser of Nature".

§ 116.

Bacon's enunciation at this time of the modern theory of heat does not seem to have affected the argument very much, even in his own mind. That this conclusion may be credible, we quote him rather fully. First, to select some sentences from his lengthy exposition of heat in the 20th aphorism of his *Novum Organum*:

"Motion is the genus of which heat is a species.

"Heat is produced by the motion of attrition without any preceding heat.

"Heat is an expansive motion whereby a body strives to dilate and stretch itself to a larger sphere or dimension than it had previously occupied.

"Heat is a motion of expansion, not uniformly of the whole body together, but in the smaller parts of it; and at the same time checked, repelled and beaten back so that the body acquires an alternating motion, perpetually quivering, striving and struggling and irritated by repercussion, whence springs the fury of fire and heat. The Form or true Definition of Heat (relative to the Universe, not merely to man's senses) is briefly this: Heat is Motion, expansive, restrained and struggling through the lesser parts. Expansion is modified: though expansion is in every direction, the tendency is somewhat upwards. As regards the practical side, if in any body you can excite the Motion of self-dilatation or expansion; and also can so repress that Motion and turn it upon itself, the dilatation therefore proceeding unequally, partly taking place, partly being repressed, without doubt you will generate heat".

Here we have, from purely *a priori* considerations, the principle of the fire-syringe (§ 41).

§ 117.

Cold was naturally opposite in many respects, but in some was similar. One similarity he does not state, but it was the root of the whole difficulty: when water froze, it expanded! Before we deal with that, let us see what he says, in his *Sylva Sylvarum,* of cold; these are his own words, for he wrote this book in English.

"The producing of cold is a thing very worthy the inquisition; both for use and disclosure of causes. For heat and cold are nature's two hands, whereby she chiefly worketh; and heat we have in readiness, in respect of the fire; but for cold we must stay till it cometh, or seek it in deep caves, or high mountains: and when all is done, we cannot obtain it in any great degree: for furnaces of

fire are far hotter than a summer's sun; but vaults or hills are not much colder than a winter's frost.

"The first means of producing cold, is that which nature presenteth us withal; namely, the expiring of cold out of the inward parts of the earth in winter, when the sun hath no power to overcome it; the earth being, as hath been noted by some, *primum frigidum*. This hath been asserted, as well by ancient as by modern philosophers: it was the tenet of Parmenides. It was the opinion of the author of the discourse in Plutarch, for I take it that book was not Plutarch's own, *De primo frigido*. It was the opinion of Telesius, who hath renewed the philosophy of Parmenides, and is the best of the novelists.

"The second cause of cold is the contact of cold bodies; for cold is active and transitive into bodies adjacent, as well as heat: which is seen in those things that are touched with snow or cold water. And therefore, whosoever will be an inquirer into nature, let him resort to a conservatory of snow and ice; such as they use for delicacy to cool wine in summer: which is a poor and contemptible use, in respect of other uses, that may be made of such conservatories.

"The third cause is the primary nature of all tangible bodies: for it is well to be noted, that all things whatsoever, tangible, are of themselves cold; except they have an accessory heat by fire, life, or motion: for even the spirit of wine, or chemical oils, which are so hot in operation are to the first touch cold; and air itself compressed, and condensed a little by blowing, is cold".

(This last sentence contains the principle of the modern manufacture of artificial ice and of liquid air.)

"The fourth cause is the density of the body; for all dense bodies are colder than most other bodies; as metals, stone, glass; and they are longer in heating than softer bodies. And it is certain that earth, dense, tangible, holds all of the nature of cold. The cause is, for that all matters tangible being cold, it must needs follow, that where the matter is most congregate, the cold is the greater.

"The fifth cause of cold, or rather of increase and vehemency of cold, is a quick spirit inclosed in a cold body; as will appear to any that shall attentively consider of nature in many instances. We see nitre, which hath a quick spirit, is cold; more cold to the tongue than a stone; so water is colder than oil, because it hath a quicker spirit; for all oil, though it hath the tangible parts better digested than water, yet hath it a duller spirit: so snow is colder than water, because it hath more spirit within it: so we see that salt put to ice, as in the producing of the artificial ice, increaseth the activity of cold: so some *insecta* which have spirit of life, as snakes and silkworms, are to the touch cold: so quicksilver is the coldest of metals, because it is fullest of spirit". (Compare §§53, 64, Paracelsus.)

"The sixth cause of cold is the chasing and driving away of spirits such as have some degree of heat: for the banishing of the heat must needs leave any body cold. This we see in the operation of opium and stupefactives upon the spirits of living creatures: and it were not amiss to try opium, by laying it upon the top of a weather-glass, to see whether it will contract the air: but I doubt it will not succeed; for besides that the virtue of opium will hardly penetrate through such a body as glass, I conceive that opium, and the like, make the spirits fly rather by malignity, than by cold.

"Seventhly, the same effect must follow upon the exhaling or drawing out of the warm spirits, that doth upon the flight of the spirits. There is an opinion that the moon is magnetical of heat, as the sun is of cold and moisture: it were not amiss therefore, to try it, with warm waters; the one exposed to the beams of the moon, the other with some skreen betwixt the beams of the moon and the water, as we use to the sun for shade: and to see whether the former will cool sooner. And it were also good to inquire, what other means there may be to draw forth the exile heat which is in the air; for that may be a secret of great power to produce cold weather".

§ 118.

In the year of Bacon's death, Boyle was born, Des Cartes was 30, and Gassendi 34. Forty-seven years later, a battle royal was in progress between the Cartesians and neo-Epicureans, with Boyle as a cautious observer. He is not satisfied by the arguments of either side.

> "I know the learned Gassendus, and divers other philosophers, teach us, that glaciation is performed by the entering of swarms of corpuscles of cold, as they call them, into the liquor. But I much doubt, whether, from this hypothesis, a good solution of our phaenomenon will be derived, since these atoms of cold seem not barely, as such, to make that expansion of the water which is required. . . . For I see, that though water will be more and more refrigerated, according as the air grows colder and colder, yet, till it be brought to an actual glaciation, all the swarms of the frigorific atoms in it are so far from expanding it, that they more and more condense it" (The critical point is actually at 4°C.) "And even that degree of cold which destroys fluidity, though it expands water, does not do it merely by the multitudes of the frigorific corpuscles, that invade the pores of the lately fluid body, since pure spirit of wine, and almost all chemical oiles, though exposed to the same degree of cold, that turns water into ice, or, as I have tried, unto a far greater than is necessary to do so, will be but the more condensed by those swarms of particles. But, which is more considerable, I have carefully observed, that, besides common or expressed oiles, chemical oile of aniseeds itself, being frozen or concreted by an intense degree of cold, will not be expanded, but notably condensed, and accordingly grow specifically heavier than before. And this was one thing, that kept me from expecting the removal of our difficulty by the ingenious explication given of freezing by the Cartesians, when they teach, that the eel-like particles, whereof they suppose water to consist, are very remissly

> agitated, and their want of pliantness makes their contexture less close. . . . Though these eel-like particles should lose all their flexibleness . . . it doth not thence appear how they should acquire so vast a power to expand themselves in spite of opposition, as we have shewn water, by freezing, does acquire. . . . Make enquiry; whether, and on what account, those little fragments of matter are cold; whether those frigorific particles, that must in multitudes crowd into water to turn it into ice, have gravity or levity, or are indifferent to both. And how any of the three answers, that may be made to this enquiry, will agree to some phaenomena, that may be produced? what structure the corpuscles of cold can be of, that should make them frigorific to that innumerable variety of bodies they are said to pervade? And whether the frigorific faculty of these corpuscles be loosable or not? As also, whether or no they be primitive bodies and if it be said they are not, whether there was not cold in the world before they were produced, and whence that cold could proceed? And if it were said, they are primitive bodies, how by putting a certain body, actually warm, into water that was also warm there should presently be produced an actual coldness".

Nor can the Cartesians explain this phenomenon, which Bacon has already typified in his freezing mixture :

> "If", says Boyle, "as a brisk agitation of a body's insensible parts produces heat, so the privation of that motion is, as Cardan and the Cartesians would have it, the cause of cold; whence is it, that, if certain bodies be put together, there will be a manifest and furious agitation of the small parts, and yet, upon this conflict, the mixture will not grow hot, but sensibly and even considerably cold?"

§ 119.

To exothermic and endothermic reactions, the evolution and absorption of heat on mixing certain substances, we shall return. But first it must be said of the expansion

of water during its freezing that we have no explanation whatever. Nothing on this point can be added to the words of Tyndall, written in the middle of the nineteenth century. He writes :

> "It is hardly necessary for me to say a word on the importance of this property of water in the economy of nature. Rumford was so impressed by it that he devoted a whole chapter to speculations regarding it. 'It does not appear to me', he writes, 'that there is anything which human sagacity can fathom, within the wide-extended bounds of the visible creation, which affords a more striking or more palpable proof of the wisdom of the Creator, and of the special care He has taken in the general arrangement of the Universe to preserve animal life, than this wonderful contrivance'. Rumford's enthusiasm was excited by considerations like the following: Suppose a lake exposed to a clear, wintry sky. The superficial water is first chilled; it contracts, becomes heavier, and sinks by its superior weight, its place being taken by the lighter water from below. In time this is chilled and sinks in its turn. Thus a circulation is established, the cold dense water descending, and the lighter and warmer water rising to the top. Suppose this to continue, even after the first pellicles of ice have been formed at the surface; the ice would sink, and the process would not cease until the entire water of the lake would be solidified. Death to every living thing in the water would be the consequence. But just when matters become critical, Nature, speaking poetically, steps aside from her ordinary proceeding, causes the water to expand by cooling, and the cold water to swim like a scum on the surface. Solidification ensues, but the solid is much lighter than the subjacent liquid, and the ice forms a protecting roof over the living things below. Rumford obviously regarded this behaviour of water as a solitary exception to the general laws of nature. 'Had not Providence', he says, 'interfered on this occasion in a manner which may

well be considered as *miraculous*', the solitary reign of eternal frost would have spread on every side from the poles. 'In latitudes where now the return of Spring is hailed by the voice of gladness, where the earth decks herself in her gayest attire, and millions of living beings pour forth their songs of joy . . . nothing would have been heard but the whistling of the rude winds and nothing seen but ice and snow and flying clouds charged with wintry tempests'. . . .

"Facts like those discussed by Rumford naturally and rightly excite the emotions . . . but in dealing with natural phenomena, the feelings must be carefully watched. They often lead us unconsciously to overstep the bounds of real knowledge, and to run into generalisations which are in perpetual danger of being overthrown. Give place to the emotions by all means; they belong to the forces of nature; but let them be wisely guided and securely based. Let not the vine of feeling twine itself round a decaying stem, lest the fall of the stem should endanger the life of the vine. Rumford was wrong in supposing that the case of water . . . was an isolated one. . . . Bismuth accurately imitates the behaviour of water. The natural philosopher, like others, and he, more than others, must stand at times rapt in wonder at the mystery in which he dwells, and towards the final solution of which his studies fail to furnish him with a clue".

§ 120.

So long as the true nature of heat is realised, it is a very great convenience to employ in calculations the idea of "quantity of heat". Temperature, or degree of hotness, was familiar to the alchemist, but he conceived quantity also; he said that, on the same fire, a large pot took longer to boil than a small one. Logically and chronologically, the measurement of degree came first, for so Man expressed climate, weather, the state of his

food and his own physical comfort. The invention of the thermometer is attributed to Galileo, and it is known that before his alcohol thermometer, which he made in 1612, he had already brought out an air thermometer. The fixed points of the thermometer are evidence of an advance in physics. In 1701, Newton suggested that the melting point of ice should be 0° and the normal temperature of the body 12°. In 1714, Fahrenheit made his zero the temperature of a mixture of pure salt and ice, took that of the body as 96° and utilised the temperature of pure melting ice as a second fixed point, at 32°. After Fahrenheit's death in 1736, the convenience of 0° for pure melting ice and of 100° for pure boiling water became more and more generally recognised. The temperature of extreme cold, the ultimate "indigence of nature" was still a matter of absorbing interest. In 1702, Amontons, with his air thermometer, arrived at the figure −240°C. This was bettered by Lambert in 1779 with −270°C. Lord Kelvin has, from purely theoretical considerations, deduced the figure −273°C., which is accepted. In 1908, by the liquefaction of helium at −268.7°C., Onnes obtained a liquid the exhaustion of which must bring us within 2½°C. of utter cold. For these temperatures are finally dependent on a principle noted by Boyle, that liquids, vapourised without application of heat, as, for example, in vacuo, suffer a fall in temperature.

§ 121.

The heat of what we call chemical action, as when a metal is dissolved in an acid, is characteristic of the bodies concerned. "Gold", says Bacon, "is dissolved

without excitement of heat; but Iron with vehement excitement; though they take about the same time". Boyle was less interested in the reason than in the possible applications of the heat. Writing to Leclerc in 1689, he mentions mysteriously "a new way of suddenly producing flame by the bare contact of three bodies, each of them actually cold". He gets high temperatures also from aqua fortis and tartar, aqua fortis and iron, iron and sulphur (moist), nitre and vitriol, quicklime and water, and he notes the high temperature produced by dissolving gold in mercury, the result of a well-known mutual attraction, for Bacon tells us that for the protection of the teeth from the action of mercury "gilders use to have a piece of gold in their mouth, to draw the spirits of the quick-silver". But then the solution in water of nitre, or of salt, or of calcium chloride (as we call it now), and of many other bodies, produced cold! Later chemical workers were to find that there is no change of state or submergence of chemical identity without an emission or absorption of heat. These heat-changes have been classified. Latent heat of evaporation is the quantity of heat absorbed when unit amount of the substance becomes gas; it is given up again on condensation. Latent heat of fusion is the quantity of heat absorbed when unit amount of the substance melts; it is given up again on solidification. The heat of formation is the heat which is absorbed when unit amount of the substance is formed from its constituents. The heat of solution is the heat which is absorbed when unit quantity of the substance is dissolved in water, and is modified by the fact that it enters the liquid state. The heat of combustion we have met already; it is the heat evolved when unit quantity of

the substance is burned. This science of "thermochemistry", which has been built up by Hess, by Andrews, by Favre and Silbermann, by Thomsen and by Berthelot, is evidently dependent on the quantitative treatment of heat. Such treatment, however, is seen to be fully justified when we consider that emitted heat is a portion of the intrinsic energy of a substance which becomes available with a change of the conditions under which the substance exists; it may also be freed in those other forms of energy with which at the moment we are not concerned.

§ 122.

The key-relation between quantity of heat and temperature, the heat specific to individual substances, was, however, the achievement of earlier workers who conceived heat as a real fluid, expansible and ponderable. This conception in itself was a real advance. It recognised the flow of heat from high levels to low, and it broke with the traditional view that heat was an opposing pole of weight. This view was inevitably held by the first investigators who discovered that metals gained in weight when they lost, as was supposed (§ 110), their "volatile sulphurs". It was held by a writer calling himself Geber, about 1300 (not the real Geber who flourished some five centuries before), who found that tin increased in weight on heating. It was held by von Sulzbach, two hundred years later, who found the phenomenon general in metals. It was categorically stated (apparently in opposition to some new doctrine) in 1553 by Cardan, who said that the increase in the weight of lead on calcination was due to the loss of fire. Liberal as he was in other directions, Cardan retained the alchemist point of view, regarding

for example the metals as efforts of nature (conatus naturæ) toward gold; so that though he probably knew of the remarkable speculative achievement of Leonardo da Vinci, which we reserve to another chapter, his view of combustion was that of the ordinary physician and astrologer. After all, the same view strongly attracted Priestley.

§ 123.

Early in the seventeenth century, however, comes Bacon's idea that heavy bodies may "subact the air into a more dense medium", and four years after Bacon's death there appeared a treatise by Jean Rey which broke altogether with the hypothesis that the addition of fire to a body lessened its weight. All the four elements had weight, he said, and the limitations of the balance must be recognised; air could not be weighed in air, nor water in water, unless indeed air were compressed or rarefied before the operation, in which event the change of weight would appear. He noticed that various oils were thickened by prolonged heating in the retort; the thickening was proportionate to the time of heating, and due to the absorption of the matter of heat, since the substances were (as he thought) "homogeneous", and did not change in themselves. He thought that this was also true of water and of air, a conclusion which one may safely guess was due to the altered appearance of water and air as their refractivity changed with the temperature. Air, indeed, he said, might become so dense that it would stick to metals heated therein, so increasing their weight.

Let it be remembered that Air was not regarded as a pure substance, and that the tenour of the thought of the time was that the nourishing "Fire in the air" was

responsible for these changes. Thus Christopher Glaser, who died about 1670, categorically attributes the gain in weight to the addition of corpuscles of Fire; Le Febure, in 1660, thought the increase due to some material of the light or heat of the flame, and Tachenius, in 1666, said that this material was acid. Duclos, working on antimony, used the old term, "sulphur".

§ 124.

Since heat passed through glass, the matter could clearly be settled without reference to the fire in the air, always provided the experimental results were reliable and the experimental equipment adequate. Becher in 1669 came to the decision that it was some fire-material to which glass was transparent that added itself to the heated metal to form the calx. Nicolas Lemery supported this decision, and Boyle, in 1673, published what purported to be experimental evidence which clinched it.

"The novelty and improbabilities of the truth I deliver", said Boyle, "seem to require that it be made out by a good number of trials". He therefore gives in full the notes of a multitude of experiments, and the reader, being equipped with the knowledge of the oxidising properties of the air, feels as though he were watching the groping of a blind giant. His first experiments were carried out with "a crucible with a little hole in it, for fumes to get out at". In a second series, metals were frankly cupelled to their calxes. In a third, he sought to demonstrate the "operations of this flame, or igneous fluid, upon light bodies sheltered from its immediate contact by being included in close vessels", but he found that glass vessels burst or melted if there were no vent,

so usually employed two crucibles, "One whelmed over another", "carefully luted together that nothing might get in or out", "some lute at the corners of the juncture to keep the fire from coming immediately at the metal". We read with genuine sympathy this cry from his heart: "If, when these things were doing, I had been furnished with a very good lute, which is no such easy thing to procure as chemists that have not frequently employed vulgar lutes are wont to think . . .", but this spirit was as lively as that other spirit whom Shakespeare called the Shrew and of whom he makes Hortensio complain "Iron may hold with her, but never lutes". Boyle could not be altogether easy about the air itself, in view of the work which Hooke was doing, and frequently wrote of his anxiety to perform the "trials" in glass vessels completely closed; but he accepted the evidence of experiments where the vessel was "a choice glass retort", where the further end was not closed, or a "vial with a long neck, the orifice being kept covered with a cap of paper (which sometimes fell off)", and the only experiments in which the vessels were reasonably air-tight, being corked, he rejected as "unsuccessful", for though the metal, here mercury, gave a little calx, there was "not enough to answer my design". Unfortunately he obtained quite enough calcination in experiments where the end of the retort was drawn out and actually fused tight some time after the contents had attained thermal equilibrium with the furnace.

These experiments and conclusions were generally accepted. The gain in weight of metals was due to some fixed fire substance. And not of metals alone. Boyle thinks there may be an application to food:

"Whether these igneous corpuscles do stick, after the like manner, to the parts of meat, dressed by the help of the fire, and especially roast-meat, which is more immediately exposed to the action of the fire, may be a question which I shall now leave undiscussed, because I think it difficult to be determined, though, otherwise, it seems worthy to be considered, in regard it may concern men's health to know, whether the coction of meat be made by the fire, only as it is a very hot body, or whether it permanently communicates anything of its substance to the meat exposed to it: in which last case, it may be suspected, that not only the degree, and manner of application of a fire, but the nature of its fuel, may be fit to be considered".

As an example of the widespread knowledge of this increase in weight on calcination, together with the insumption of some new energy or quality, let us quote Evelyn:

"The *Calcination* then of *Earth* alone, not only disposes it to produce great Variety, but if it be intense, increases the very Weight of the Mould; whether from a certain *Magnetism* which it thereby contracts, (which fortifies it to draw the proper Aliment more powerfully) or upon what other Account, let the Curious examine".

§ 125.

The explanation of this increase in weight came one hundred years later. It was due rather to the genius of Lavoisier than to his balance, on which it is conventional to heap high laudation. He praises it himself, it is true, adding, "I do not think any can compare with it for precision and sensibility, excepting those made by Mr. Ramsden of London". But it had not been the sensitivity of balances that had misled earlier workers or achieved Lavoisier's success; it was the absence or presence of the concept of that gas which Scheele called "fire-air" and

identified with the pure air of the empyrean, lying between the heavens and the middle region. Moreover, it was Lavoisier, by an irony of history, who resuscitated the idea of a matter of fire. It explained the difference in state of a solid and its vapour as a chemical difference; the vapour was a combination of the solid with this matter of heat. Thus hydrogen, before evolution, was solid or liquid : when it was freed, it took up caloric and became "hydrogen gas". The name appears to have been supplied by Berthollet.

§ 126.

The caloricists were at first very cautious. "The *cause* of heat", says Berthollet, "which I denominate caloric". Lavoisier writes, too :

> "Apart from the fact that this expression fulfils our object in the system we have adopted, it has still another advantage; this is its power of being adapted to all kinds of opinions, since, rigorously speaking, we are not even obliged to suppose that caloric is a real substance; it suffices that it may be any cause whatever which separates the molecules of matter, and we can thus consider its effects in an abstract and mathematical way".

In reading the works of these men, of whom Lavoisier says "Frequent intercourse and the habit of communicating our ideas or observations and our way of thinking to each other has established between us a sort of community of opinions in which it is difficult for everyone to know his own", it becomes clear that familiarity with the idea of this caloric reached the point of a firm belief in its existence; yet their work was so sound that it forms the foundation of modern heat theories, in which only the name of caloric has disappeared. In one regard alone does Lavoisier allow this actual belief to betray him :

"Although caloric penetrates freely through the pores of every substance in nature, it can only do so progressively, and in a given time; hence when the quantity disengaged at one moment is too large to get through the pores of the surrounding bodies, it must necessarily act in the same way as ordinary elastic fluids, and overturn everything that opposes its passage. This must to some extent take place when gunpowder is set on fire in a cannon; since, although the metal is permeable to caloric, the quantity disengaged at one time is too large to find its way through the pores of the metal. It must therefore make an effort to escape on every side; and, as the resistance all around, excepting towards the muzzle, is too great to be overcome, this effort is employed for expelling the bullet".

Of a furnace he writes : "The upper orifice must be large, lest the too sudden expansion of that highly elastic fluid should produce a dangerous explosion". Having slipped, Lavoisier now "crashes" : the caloric also has a repulsive force acting between its own particles, a caloric of the second dimension : "The caloric produces a second effect, by means of the mutual repulsion exerted among its own particles".

§ 127.

Elsewhere in this magnificent structure, we can only look to the nomenclature for any antiquarian interest. Thus "Real solutions are produced by fire, by introducing and accumulating a great quantity of caloric between the particles of bodies. This solution in caloric is usually called *fusion*". Noticing that a thermometer might register a temperature higher than that of the air around it, they said that it "can absorb the radiant caloric which does not combine with the air". They said that radiant caloric was "absorbed with greater facility" than was light, since it possessed "less of the qualities of eminent

elasticity", or, perhaps, was "endowed with less velocity". Light might add itself selectively to the ingredients of a mixture; heat added itself impartially, varying only in respect of the "capacity for heat" of the substance; but when light had been added, it differed in no way from fixed caloric. Calces had to be brought to a red heat to liberate their gas; this showed that red light was an essential constituent of the gas. Similarly, as light was separable into different rays, though these differed little in chemical potency, yet on muriate of silver fifteen seconds of the violet ray was equivalent to twenty minutes of the red. By analogy, radiant caloric contained several substances really different, and was a genus to which many species belonged. They said they were unable to determine whether light were a modification of caloric or caloric a modification of light. That magic of the Moon-element, selenium, which we call Television, was yet to come. That magic of silver, the Metal of the Moon, which we call Photography, was only about to be conceived.

§ 128.

Similar results, with much less justification, had been reached by the phlogistonists who identified phlogiston not only with hydrogen, but with light and with electricity. But whereas the phlogiston theory could be killed with the balance, the caloric theory could only be killed by proving that the heat from friction was inexhaustible except in respect of the energy employed. This was done in 1778 by Rumford. Davy silenced the last doubters by producing water from two blocks of ice rubbed together *below freezing point* (it was otherwise an old experiment), since the caloricists allowed that ice contained less caloric than water.

§ 129.

The caloric theory was an unconscionable time a-dying and in 1829, Henry, in one of his text-books, says that atoms have probably atmospheres, which are heat. In 1880, Tyndall was still expressing annoyance with the common use of such terms as "heat capacity". We have already shown why, as an empirical aid, the idea of quantity in heat is invaluable, and in our constant use of the "calorie" and "therm" we still pay unconscious homage to the careful founders of the thermal science. "The *cause* of heat", says Berthollet, after all, so that caloric was but another name for Energy and we may measure Energy in calories with the same complete justification as attaches to coulombs or to foot-pounds. No one nowadays will confuse the impalpable with the immeasurable. After all, did not the savage himself measure Space, Time and Deity?

CHAPTER VII.

ALL AIR AND FIRE.

His raptures were all Air and Fire.—*Drayton on Marlowe.*

With ho! such bugs and goblins.—*Shakespeare's Hamlet.*

So, stumbling and uncertain in its gait, Air struggles upward from the baser Earth, mingling its being with the fluid heaven of Fire.—*Tibullus.*

§ 130.

Old ideas about the atmosphere had to be demolished before the relation of air to combustion could be even suspected. The effluvium was known. It was not essentially different from a breeze. It was necessary first to adopt the Epicurean notion that the Air was not only a receptacle of "effluviums", but of like nature. Then it was necessary to develop a criterion by which the palpable and substantial constituents of the atmosphere might be distinguished from radiance and immateriate virtues. When Physics had done this, Chemistry took up the torch. Such were the common beliefs about the Air in the period prior to the formulation of Boyle's Law and the recognition of oxygen, that it may be well to preface this chapter with the reminder that there were in Europe executions for witchcraft as late as 1793, that Ferrer died bravely for his "heresy" as late as 1909, and that within living memory the majority of Europeans unquestioningly accepted a tenet of their religions that on a certain day the bodies of the dead would ascend to the Middle Region to meet the

Son of God "in the Air". The great thinkers of the seventeenth and eighteenth centuries were too scientific to scorn beliefs because they were vulgar notions; they knew, as we do, that many popular ideas, like kitchen medicine, cover empirical knowledge and experience of the highest value. Moreover, these beliefs were not incongruous with the scientific basis of the time. Their attitude, as for example Boyle's towards the gnomes, was that these matters were not proven. In the contemporary poets one character believes and another does not; one mood accepts and another rejects. A good example of that is to be found in Shakespeare's treatment of ghosts or of stellar influences.

§ 131.

The atmosphere was the great receptacle of things that disappeared from sight, for the memory and idea of them lived on as dreams lived. That "secreta facultas", as Lucretius called it, that genius which distinguishes one place from another, one object from another, could not die. To say that cinnabar was made of mercury and sulphur did not account for its "earthy" properties, nor was one piece of pyrites in every respect like another. Every manifestation of energy still argued a spirit. Orthodoxy believed with Origen "that nothing is done without the aid of viewless labourers and servants". Moreover we have seen that every object of the senses, like the body of man himself, held a "spirit in prison". This spirit, when released, must traverse the Air. And what was the Air? "Air is not an element", says Vaughan, "but a certain miraculous hermaphrodite, the cement of two worlds and a medley of extremes. It is

the sea of things invisible, and retains the species of all things whatsoever".

It was a Region, bounded on the outer side by the fiery firmament, or enclosure, of Heaven, and, within, by the Ocean and the Earth. On its borders, there was much commerce with its neighbours, the Upper Air or Empyrean partaking of the nature of Fire, and therefore, by a natural lapse in logic, very pure, and the Lower Air, shadowed by the meteors of the Middle Region, holding a suspension of dusts and dews from Earth and Water. Ideas about the Air took form as analogies conceived during hours of leisure when, yielding to the eternal fascination of water, man peered into dewponds and pored over running streams. Legends of the "parting of the waters", easily reproduced on a small scale, were given a counterpart in the Air. Plutarch describes in *Flamininus* the shout of joy of the Greeks when Titus Quintius, having overcome Philip of Macedon, restored to them all their ancient privileges :

> "Crows that were by chance flying over the course fell down dead into it. The disruption of the Air must have been the reason, for the voices being numerous and the acclamation violent, the Air breaks with it and can no longer support the birds, but lets them tumble as one that should attempt to walk upon Void".

Bacon cautiously accepts this explanation and ignores Plutarch's alternative :

> "unless we should rather imagine them to fall and die, shot with the noise as a dart. It is possible, too, that there may be a circular agitation of the Air, which, like marine whirlpools, may have a violent direction of this sort given to it from the excess of its billowing".

Plutarch indeed prefers this, and when he comes to write of *Pompey*, says:

> "The multitude, being extremely incensed, made such a loud outcry that a crow flying over the market-place just then was struck and dropped down among the crowd; whence it would appear that the cause of birds falling down to the ground is not any rupture or division of the Air causing a vacuum, but purely the actual stroke of the voice, which, when carried up in a great mass and with violence, raises a sort of tempest and, as it were, billow, in the Air".

There were ways, too, in the Air, as there were paths upon the sea. Shakespeare's Macbeth speaks of its "sightless couriers", no mere "poetical" metaphor to the Middle Age which believed that "Virgilius" made in the atmosphere bridges of air over which he travelled with his prey. The real Virgil himself has a charming use for the image: he says that in stormy weather, those puzzling creatures, the bees, "often take up little stones as unsteady vessels ship ballast to confront a tossing sea; with these they poise themselves in their travels through the void fields of the Air".

§ 132.

A speculation of more immediate importance to human welfare was the analogy that stagnant air was unhealthy while air in motion was good. The fevers from marshes were due to the lack of motion, and when water was muddy it was still or its motion was sluggish. The fitful light of the marsh-damp was a proverb of Evil noted by Persius, and Catullus wishes his enemy into "just that part where the boggy slime is the bluest and deepest". The unhealthiness of bad air, by parity of reasoning, was due not only to its stillness, but to its

stiffness : it was clogged with gross exhalations. It was full of evil dews or dusts. Thus magicians could cause local epidemics by scattering powders of appropriate composition, appropriately conjured. They were in a similar category to those powders which in Milton's masque were sprinkled in the Air as spells, or to that dense dust which in Dante explained darkness, or in Shakespeare thickened the light when the crow made wing to the rooky wood. Moses and Aaron sprinkled ashes which became boils and blains on man and beast. Livy says that in the consulship of Claudius and Halelius, one hundred and seventy persons were executed for similar acts. Seneca considered that pestilences could certainly be artificially produced. In Charlemagne's time, emissaries of the Duke of Benevento were put to death for strewing these powders in France. One of the constituents of this death-dust was the basilisk. Yet in early times plague was almost always the result either of a battle or of a siege; so it was often attributed not more to underfeeding, unsuitable diet, bad sanitation and slow putrefaction than to the fact that so many persons in so small a space were breathing their vapours into the Air. An act of Elizabeth's recognised this danger. In 1580, she prohibited the erection of any new dwellings within three miles of London, and forbade the sheltering of more than one family in one house. So Athens in the time of Pericles, besieged by Archidamus and the Spartans, lost through plague "all the flower and prime of its youth and strength", and the inhabitants believed that

> "the occasion of the plague was the crowding of the countrypeople together into the town, forced as now they

> were, in the heat of summer, to dwell many of them together even as they could in small tenements and stifling hovels, and to be tied to a lazy course of life within doors, whereas before they lived in a pure open and free air. . . . They are kept pent up like cattle to be overrun with infection from one another".

Dirty personal habits have always been a communal danger when a religious fetish was attached to them. Apollonius taught a contempt for hot water to eager disciples who did not, as he did, wash carefully in cold. Agnes was "canonised" for refusing to bathe. In the terrible descriptions of the plague in Thucydides, Lucretius and the Georgics, the idea of this contagion therefore is dominant. "To the very birds, the Air becomes pernicious", says Virgil, "and falling headlong, they leave their lives beneath the lofty cloud".

§ 133.

Plague, then, was a tincture, or solution, or mud, in the Air. How intimate was the analogy may be realised from the old phrase of "drinking tobacco", where we now speak of "smoking" it. Plague spread in air as poison spread in water. The logical protection and cure was fire, the principle of motion. Thus when Aeneas prepared to dare the dangers of the underworld, the home of all things evil, the "glooms of Orcus"—for they shunned the Light—he invoked the sun-god, and was given the charm of the golden bough with the golden leaves. He was about to invade the very source of plague effluvia, and he was to take fire with him. Virgil compares it with the yellow-berried mistletoe, and describes it as growing at the very mouth of the stagnant lake, "stinking Avernus"; for the exhalations that rose

into the atmosphere made a poisonous sky-zone, forbidden to the flight of birds. He entered desolate halls and empty realms where silence reigned in night. There were griefs, cares, diseases, age, fear, famine, poverty, death, toil, sleep, lust, war and discord; there were dreams, drowsy under the leaves of the aged elm: no vine twined itself about this exile from the sunny orchard; there were monstrous forms. Charon is hypnotised by the golden bough, and brings to him his lead-coloured barge. This may all be read accurately not as an allegory, but as a description of ideas long to be held. To the middle age, plague was a sluggish cold. So Caxton in his *Golden Legend* (Westminster, 1483) writes of St. George's dragon that he dwelled in "a stagne or ponde lyke a see" and "envenymed alle the contre". "Whan hee came nyghe the citte, hee venymed the peple wyth his breeth". (But the people were baptised, the dragon slain and a church built, "in the whiche nowe sourdeth a founteyn of lyuinge water whiche heleth seek peple that drynke thereof".)

Had we followed Aeneas further, we should have come to smoky and corrosive fire, for the association of plague is with every concept of evil and after that with inertia, with earth, with heaviness, with stagnation, and with cold. That the plague effluvium was breathed out of the Earth reflects the natural opposition of Fire and Goodness on one side and Earth and Evil on the other. This fear of the Earth was held side by side with adoration of the Earth-mother. It was another aspect of the Earth, that was all. The two aspects were united in an extraordinary way, described by Tacitus, in the worship of Hertha on the island of Heligoland (thence called "Holy

Island"). Hertha would visit her people, the period of her stay being an era of love and gold; wearied then, she retired to the lake within her holy grove. Here she disappeared, and slaves were slain. "Hence", Tacitus concludes, "proceeds a mysterious horror". The relation between plague and cold lies only in the intermediate idea of earth or heaviness. Plutarch says that when the autumnal equinox is past, the Air "closes in"—a simple and vivid recognition of the nearer proximity of the winter Cloud Level, the superior brilliance of the winter Stars. There was another aspect, however. When cold was really bitter, it was a manifestation of fire. Plague throve in a normal, neutral temperature, the temperature which in some transitory systems had meant (§ 115) equilibrium or health. A sultry summer was its friend. Shakespeare's Faulconbridge says "Some airy devil hovers in the sky And pours down mischief". Fire was a cure because it was keen. So, in medieval times, we find that in winter the natural fire of frost stopped the plague. In summer, they tried to stop it with artificial fire. In London in July, 1665, when about two thousand persons died each week, there were great fires to be seen everywhere, and the poignant symbol of the cross was daubed as a talisman on every door. It was red, of course.

§ 134.

Persius did not destroy astrology when he pointed out that twins of unlike character had yet the same horoscope. So one belief, struggling among many, was that the heavens "poured down the plague for perjury". It was the "planetary plague", mainly of Saturn, and Clement VI bowed to the older connotation of the cross

when he prayed to the four points of the compass as if, a new Ezekiel, he would invoke the breath of the four winds to revivify the slain. Thucydides was one of the few victims of a plague who recovered from it. It started in the summer of 430 B.C., and men of that day said that its source was the Soudan. It recurred frequently throughout the Peloponnesian War, and the Athenians put it down to wilful reservoir-poisoning, for there were as yet no wells. It was believed in the Middle Ages that the plague returned in cycles of thirty years—even Mead did not dismiss the idea with ignominy—and a similar deference to the number, three, was shown in the theory that it originated (in China) in the year 1333. The interest of this quite baseless explanation is that it teaches that the plague had its sources in a mist, which was, as we have seen, the aerial homologue of mud. Some survivals of the fire-cure persisted until recent times. The red armlet of vaccination was originally a mascot against witchcraft and the plague. Nowadays it marks their victim. Firebrand Sunday at Dijon originated in processions of Burgundian peasants who drove away bad air—and bad spirits—with their lighted torches of straw. So too in Ireland on Midsummer's Eve, not only "to purify the air, which they think infectious", but to expel "all the devils, spirits, ghosts and hobgoblins which fly abroad this night to hurt mankind". But in those days, even a Protestant like Luther—since in many respects the Reformation simply substituted Sinai for Rome—believed that it was evil spirits who "poisoned the air or otherwise infected the poor people by their breath and injected the mortal poison into their bodies"; for Origen had also written that the rôle of demons was "to cause famine,

the sterility of trees and vines, excesses of heat, the aerial poison that destroys fruit, kills animals and brings plagues upon men".

§ 135.

Now flame was the natural habitat of good spirits. Uatchet, the Lady of Flame, was the very eye of Ra. The Word, or Soul, or Name of Jehovah was like a Fire; but its vehicle was the Spirit, and the Spirit "proceeded". To holy men like Ezekiel or Philip it might even be a magnet as well as a vehicle. Furthermore, Jehovah had not only a Spirit, but spirits: it may be recalled that at the annunciation of the birth of Samson, "when the flame went up toward heaven from off the altar, the angel of the Lord ascended in the flame". The belief in the opposition of fire and the plague as the old conflict between good and evil led to the conclusion that plague might simply be exorcised, a belief that was turned to good profit. It was a preventive as well as a cure; Richard Bankes informs us that Rogation Week is the time proper to prayers "that He will vouchsave to pourge the ayer. For this cause be certaine Gospels red in the wyde felde amonges the corne and grasse, that by the vertue and operation of Goddes word, the power of the wicked spirites, which keepe in the ayer and infecte the same (whence come pestilences and the other kyndes of diseases and syknesses) may be layde downe, and the aier made pure and cleane, to th'intent the corne may remain unharmed, and not infected of the sayd hurteful spirites, but serve us for our use and bodely sustenance". Side by side with this newer fetishism, however, there was still the old belief in the efficacy of the very pure fire from wood. This was called the "need-fire", and it

was essential to its success that it should be kindled by wood-friction. The last recorded driving of horses and cattle through this kind of bonfire in our own country was at Perth in 1826, but Tylor states that "need-fires" were kindled much later than that in Sweden and elsewhere.

One of the earliest references to these "hurteful spirites" in England is that of Bede, who speaks of the visitations of the plague in and before the seventh century of our era. It was a time when prayer would change the course of a wind too helpful to incendiaries. It was a time when rumours were "wicked spirits flying about the whole island". "The pestilential state of the Air destroyed thousands of men and cattle". Yet in our country there has never been that complete moral degradation, that utter rout of ethics, with which the plague has been associated in larger land-areas. At Eyam they still commemorate year by year on Plague Sunday the seventeenth century heroism of a tiny village that, finding itself plague-stricken, isolated itself completely from its countrymen, no single inhabitant attempting to escape the communal decision.

§ 136.

The idea that "spirits of health" brought with them "airs from heaven", together with the principle of Like to Like, led to the belief that good spirits were attracted by pleasant odours. This is not quite the same thing as the Egyptian view that the odour of the god was delicious and that as the soul of the dead pursued its journey through the underworld, its odour became more and more approximated to that of the god. Yet this very association was adopted by the Roman Church in tales

about its saints. The sacrifices offered to gods in ancient times were generally lighted with the wood specially sacred to the particular deity, white poplar for Jupiter, or for Ceres the smoky pine, speaking to her of her lost Persephone. The Arcadian oracle seems to have been unique in prohibiting all but smokeless fuel. Incense was naturally regarded as the purest offering. Thus the gold, the frankincense and the myrrh which the Magi offered at Bethlehem were the supreme symbols of the Fire they came to worship. In the Hebrew religion where, as we have seen, the symbol was Blood, the god delighted especially in the "sweet savour" rising from flesh cooked on the altar, but he also was regarded as requiring a strict observance of the established formula for the temple incense; strange fire won little favour.

Evil spirits and volcanic deities, on the contrary, brought with them whirling "blasts from hell", cold or corrosive, or the stinking mists of plague. We have seen in § 54 that Charon and Pluto were given vents for their eructations, but Set or Typhon was a god older than either and he, far back in the earliest days of the ancient Egyptians, had a breathing-hole in the Serbonian Marsh. One of the constituents of the stink associated with devils was usually the fume of rock-sulphur—an element of confusion, since this is a matter as preservative as salt, or as the sap of cedar. It was not that the demons loved the stink; if that had been so they would have been happy—a cogent and final consideration. They hated vile smells with a geographical unanimity that is somewhat astonishing. In *Tobit*, Asmodeus, "as soon as he smelt the odour, fled into Upper Egypt": it was the odour produced when young Tobias with this special end in

view fried the entrails of a fish. Then, too, in systems where the older gods became demons, as among the Churchmen, they naturally still liked incense. Two demons examined by Sulpicius Severus admitted frankly after some pressure that one of them was Jupiter and the other Mercury. Among the Churchmen, therefore, incense might actually hold associations of wickedness, and we find Tertullian prohibiting his flock from the trade of selling it; it had led them into a grave remissness in the sacred duty of spitting upon the pagan altars!

This detestation of filthy odours by the spirit world provided another "cure" for the plague. Physicians provided for their patients canisters of pungent spices, but themselves were more fortunate: the patient died; the doctor lived. The reason for this was that since one hand was already necessary for the proper deportment of the professional wand and the other must needs be free, the physician's own canister was strapped round his nose—it was a pointed, conical affair, so they called him a Beak Doctor—and this generally provided a reasonably efficient respirator. It was supposed that the pungency of the hot spices pierced the air and put it into healthy motion; and that any other sufficiently powerful stench would have a similar beneficial effect. Willis records that the families of tobacconists and smokers were free from the plague So Virgil had taught the husbandmen to drive away snakes with the fume of the fetid gum-resin galbanum, and now the similar substance asafoetida was called in to expel both demons and the plague. We read in the autobiography of Benvenuto Cellini how he watched a wizard call up "legions of devils" by incantations and sweet smells; they completely threw off his control,

however; and, frightened to his marrow, their would-be master made for the censer which contained the resin of dispersal. His panic caused him to imitate without premeditation the broad jest of Amasis in Herodotus; and the spirits fled pell-mell before the censing could be begun.

This joke of Cellini is repeated because it is an important contribution to our reconstruction of the thought of the age. It was a common practice in Western Europe to begin the day by a deep inhalation of the odours from the fermenting faecal matter in the closets, just as in Eastern Europe filthy male goats were kept close in the sick-room. Many kindred remedies have been attributed to the teaching of Paracelsus—parabolic as it may have been—that in excrement was the greatest secret of Medicine. For a reason which will appear, we shall take his words at their face-value. He certainly taught that the fat extracted by distillation from the human corpse was a balsam and specific against gout, itch and leprosy. He said that it cured wounds. We have quoted him on the basilisk, but he applies the name basilisk also to the life generated by the putrefaction of eggs and of the human sexual issues. Inoculation by serums would have made him very happy. He made styptics from the intestines and plasters from the bones. The knowledge that phosphorus and oxygen might be obtained from derivatives of urine must have impressed the alchemists to an extent that we can well understand. Many years later Benjamin Franklin writes of it as a cure for chapped hands. Many centuries earlier Strabo, Diodorus and Catullus make it clear that it was employed in Spain as a dentifrice and cosmetic.

Nor was it at this time a stock resource of the alchemist alone. He labelled it according to its source and age: "Take old urine, passed away from its deposit": and the urine of a young virginal boy was the very best preservative for gold. But we find Boyle also differentiating gravely between the produce of a servant and the produce of a gentleman, though at that time in one house they almost certainly consumed portions of the same food.

When we attribute the origin of these ideas to Paracelsus, however, we have hardly done more than find the stream; we have barely begun to trace the stream to its source. Its source was the Egyptian teaching of the sanctity of the human body. There was no issue or emission of the human body, male or female, living or putrid, with which they failed to connect some legend of creation or of medicine. The power of spittle was widely accepted in historical times, and Jesus was able to employ this belief in one of His healings. In the legends, it had a nature dependent on its spells: it might indeed be healing, as when the spittle of Thoth immediately healed the eye of Horus after his fight with Set; but it was the spittle of the Sun-god himself that Isis made into a serpent for his undoing. The spittle of Horus was the generative Rain, and the water from his eyes filled the olive-tree with the essence of its fruits. Similarly a glance, or a breath, or a tear from a god might engender, might preserve, or might slay. As to the foul and filthy possibilities inherent in the researches of the ambitious physician along these lines, imagination cannot run beyond the facts. The laboratory became a charnel-house and the medical grave-rifler a disseminator of the plague.

Now Isis, like her priestesses, dispersed demons by the rattle of her sistrum, and the Romans drove away illness with songs and the Moon-eater at eclipse by the noise of their cymbals. So in medieval France during such "visitations" (for, like an illogical undertone, there was always the feeling of divine punishment and a consciousness of the presence of Tisiphone or of an angel who "poured out his vial into the Air") they shook the Air by an unresting ringing of bells and a continuous discharge of cannon, blunderbusses and muskets. So in much later days they drove out fever from among the savage natives of the Southern Argentine; so in Mexico the priests repelled the evil demons, not only by fires, but by horns, gongs and the tympani of serpent-skins. The crowing of a cock—and, even more, the flapping of its wings—has always been held to dissolve enchantment, for it banishes darkness; and the efficacy of music dates back at least to the story of David and Saul. If what Lorenzo told Jessica be true, or Daphnis Chloë, it goes back very much further.

Inevitably men also believed that some opposite pole of the noise that demons so disliked, by converse would attract them, as men have piped to birds. Yet examples of this feeling have left few traces in literature. The Roman "rhombus" was a reversible machine. The Mexican rattle, also, shaken one way brought spirits, shaken another way dismissed them; but that is almost incantation: and incantation has always been powerful enough to do either. In Persius it is said to make even the snake swell up and burst and Tibullus says that but for the clashing of the brasses it could drag down the Moon from her chariot. The tale in Paracelsus about

the Spanish necromancer's bell is almost unique; and the emphasis, too, is on the correspondence of its dome with that of the firmament, for in lieu of planets it was inscribed with cabalistic signs. Apollonius had his own way for dispersing spirits. He cursed them heartily.

We have mentioned the Mexican plague-fires, reminiscent of the old purifications, as where Tibullus rather sneers at the drunken shepherds, who leap through their fires of straw. Inevitably the plague-fire appeared in Medieval Europe. Its success caused its continuance; and no one seems to have questioned its efficacy until Mead pointed out that whereas a bright flaming fire was very well, a smouldering heap only scattered the filthy steams to fresh pastures; after all, one of the great mainstays of the plague was what the alchemists called the fire of dung. It was not possible, however, for everyone to follow the example of Pope Clement VI who during the Plague lived constantly between two fires, but the identification of Fire with the various "sulphurs" led to some additional sound methods. In England, by the time of Defoe's *Journal,* there was a common revival of the ancient practice of fumigation, as distinct from censing, and this was very sensible even if it were no very great advance on one of the oldest practices of the laundress or even on Odysseus' fumigation of his hall with the smoke of rock-sulphur after the massacre of the suitors. Defoe's physician is depicted as advising him "never to open a window, shutter or curtain without first making a very strong smoke with resin and pitch, brimstone or gunpowder and the like". People shopping for the household carried bottles of scents in their hands, and the butcher received their moneys in a jar of vinegar. All

these bodies, of course, were "sulphurs", vinegar being the "vitriol" or "incombustible" or "fixed sulphur" of wine. If we transcribe his view of the plague, it is well to remember that it was published as much as twenty years after the death of Hooke:

§ 137.

> "The calamity", he says, "was spread by infection; that is to say, by some certain steams or fumes, which the physicians call effluvia, by the breath, or by the sweat, or by the stench of the sores of the sick persons, or some other way, perhaps beyond even the reach of the physicians themselves, which effluvia affected the sound who came within certain distances of the sick, immediately penetrating the vital parts of the said sound persons, putting their blood into an immediate ferment and agitating their spirits to that degree which was found . . . and I cannot but with some wonder find some people . . . talk of its being an immediate stroke of Heaven, without the agency of means; . . . likewise the opinion of others who talk of infection being carried on by the air only".

At this point, Defoe breaks into italics to express his almost inexpressible contempt for the theory of the bacillus; he continues:

> "by carrying with it vast numbers of insects and invisible creatures, who enter into the body with the breath, or even at the pores with the air, and there generate or emit most acute poisons, or poisonous ova or eggs, which mingle themselves with the blood, and so infect the body: a discourse full of learned simplicity, and manifested to be so by universal experience".

For there had long been a dim sense that the plague did not merely "infect" by diffusion, for it multiplied. All things had central souls or seeds. "The weather is

blamed" Nicolo Machiavelli had written in 1527, "and the air, which is said to *teem* with plague infection. It is stated that it was just the same in 1348 and in 1478".

It was an unscientific dogmatism similar to Defoe's that had betrayed Harvey into the denial of spirits in the blood.

The bacillus theory is supposed to have been based on the story that Hippocrates, believing that the plague was carried by insects, fired whole forests to destroy them, and it may also be found in Varro, who says that "when marshes begin to dry, they engender a multitude of invisible insects which are introduced into the mouth and nostrils with the inhaled air and occasion serious illnesses". It was definitely stated by Athanasius Kircher, of Fulda, who was professor of Mathematics and Philosophy at the University of Würzburg. He says:

> "The plague is nothing but a multitude of small animals and diminutive worms which fly about in the Air, and when drawn into the body by the action of breathing they vitiate the blood, impair the spirits, and finally gnaw into the flesh and glands. . . . Protection against them may be attained by lighting large and flaming fires, by means of which their wings, feet or probosces etc. are burnt off so that they can no longer fly about and vitiate the blood of human beings and gnaw their bodies".

§ 138.

Witchcraft was inevitable. Given the primitive outlook, it was a logical necessity. You suffer pain or ill-fortune, the very pain or ill-fortune that you conceive your most successful enemy to have wished you. You are "ill-wished". You may try to return it, for the apparatus of the Little Model is available to all; but—

perhaps quite unwittingly—he has established the supremacy the fear of which is already the basis of your resentment. You accuse him, and the process of making him a witch has begun. His own conscience is not clear, for he has wished this very thing, and his supremacy becomes a conscious one. A real power comes to him, a power that grows on his own growing confidence and his awed neighbours' fear. All the environment of hypnotism and faith-healing has been created, and his position is now permanent. We say *his* generically. There has always been wonder, in the words of James I, "what can be the cause that there are twentie women given to that craft, where ther is one man? The reason is easie, for as that sexe is frailer then man is, so it is easier to be entrapped in these grosse snares of the Deuill, as was ouer well proued to be true, by the Serpents deceiuing of Eua at the beginning, which makes him the homelier with that sexe sensine". But women are also more numerous in the formal worship of Heaven, and the stupid, non-devotional religious sense—as Paul indicated at Athens—is closely akin to the superstitious. The witch-hunters never forgot that it was a woman who said to Saul, their father, "I saw gods ascending out of the Earth".

Then comes Rumour, a crowd-psychology that need only be mentioned to explain the growth of legends. As in the Great War, they saw Russians everywhere (as, indeed, since the War they have seen everywhere their fingers), so legends grew. If it is difficult to persuade the Camera to record the truth, what shall we say of the Eye? We do not *see* the optical image on the retina: we see a translation of it, a commentary upon it, and

that commentary is not only the product of our own previous experience: it is the product of our own previous information and imagination, true or false. Thus it is perfectly accurate to say that we see things that are not there, things that the camera would not record. In other words, we make mistakes of which it would be impossible to convince us. Men saw spirits gazing at them from surfaces in the stream, from hollows in the tree, from crevices in the rock. They saw witches in the nightly columns of grey vapour that rose from their brooks and ponds and middens. They *saw* them; and the testimony of eye-witness, distorted and anew distorted on the legion lips of the community, was added to the corpus of the priestly knowledge; for thus witchcraft entered the holy writings of the various peoples and a belief in witchcraft became a religious duty.

Then with heavy feet came Rome, teaching Aristotle and Aquinas with the mallet and the ram. The sense of polarity balanced God with Devil, and over against the holy servants of the One—who in genuine Aristotle dwelled at the common peak of all the poles—they necessarily opposed the abandoned wretches who were the slaves of the other. Then began a grey tale which an historian might be forgiven for burking, were it not for the insistent and insidious threat of its repetition. One development of the worship of Isis sought to uproot the other. Rome persecuted with tortures that in their rudiments were derived from the Greeks and Latins—peoples that with grimly unconscious humour had called the Goths and Huns and Medes "barbarian"—and then, just as to-day innocent lunatics will give themselves up to the police as guilty of murders of which they do not know

even the first details, so the mentally deficient flocked to the coven of the witches and boasted of their imagined crimes. There were witch-panics, and during these it was sufficient to accuse no matter whom; it might be a Joan of France, the only "witch" that Rome has rued; Rome did the rest.

The staggering uniformity of the evidence is explained very simply indeed. The accused person was tortured until he gave the answers that were required; tortured until in agony he accused any innocent person of whom his examiners desired to gain control. Thus medieval witchcraft fits the Peripatetic system in every detail. In this abomination we have indeed a picture of "Satan divided against Satan": and his kingdom did not stand.

We have noted already that some secrets of the Magi and of the alchemists—a knowledge dangerous in itself during the eighteen dark centuries of Roman night—percolated into the hands of charlatans and criminals. It was neat and simple to identify this criminality with witchcraft.

It was Gregory IX who, in 1231, started the burning of "heretics", and Alexander IV who authorised sorcerers to be punished—if they were heretical! So in 1316, the body of the dead alchemist, Petrus of Abano, was exhumed and burned. He had taught medicine at Padua and had ideas; thus he was naked to any accusation of sorcery and the accusation had accordingly been made. By 1404 the "Holy" Office had burned more than 30,000 witches! When the Roman Church, nowadays so sensitive to slight or offence, writes of its martyrs, it does not mean these. It will be falsely asserted that they were

strangled before they were burned—as if that were an extenuation—and nothing will be said of the tortures prior to death. But they have given evidence against themselves. About 1431, many details of these holy crimes appeared in Nider's *Formicarius,* a survey of witchcraft, based on the agonised gaspings of tortured masses of bleeding flesh, once human, who were not granted the eagerly anticipated luxury of death until they had invented some confession satisfactory to the pious monks who worked the sacred rack and the saintly pincers. Similar inventions were published in Sprenger's *Malleus Maleficarum* (1486), and in Rémy's *Demonolatry* (1595), a work described in the title as "containing wondrous histories of witches burnt alive (*sic*) in the Duchy of Lorraine to the number of 800, a book most useful and pleasant to read". In 1608 came Guazzo's *Compendium Maleficarum.* All these contained shocking records of libidinous sadism. Women were delivered to these priests naked and bound, helpless as a stolen dog in the hands of a vivisector—only these examiners held a Latin tradition, and the Latins had vivisected their slaves. The justification of all this was Roman Law. The runaway slave might be tortured and then crucified. Some of the examiners were no doubt honest in the light they had; but there were others from a lower hell, sanctimonious thugs who believed in catching "witch-tainted" maidens young. Some of the tenderest age were raped by their celibate gaolers, tortured until they gave evidence that they had had carnal intercourse with the Devil, and then burned on the strength of this confession. The writers of these books obviously believe that during their imprisonment these poor trapped girls had done what they confessed.

And in 1931, this Church is informed by its Head that it is a lamentable thing that Shelley—Shelley!—should ever have been born. In 1931, this Church informs a grown-up world that Civil Marriage is a Public Sin.

The Puritan regimen is habitually regarded as the pole opposing the Roman Church; and it is too often forgotten that it was also necessarily the child of the Roman Church, even if it were something of a throwback to its Mosaic grandparent. In the present matter, that is the governing consideration. James I calls the Roman Church "their rotten religion", and describes their supposed power of casting out devils—which he accepts—as similar to the power that Judas must have had; yet, he adds, because they are wrong about the Sacraments, that does not make them any less right about this matter of witchcraft. So James persecuted with the best, and but for the comparative infrequence of the fetid taint of sexual outrage, there is little to choose between the Roman Churchman and the Scots Puritan. It is true that after the occasional exit of frantic half-charred victims from the fire, the Puritans did sometimes resort to a prior strangling. Only a century later, the Puritans were able in America to harry the Friends on the same ostensible grounds as the Roman Churchmen had persecuted the Protestants.

So finally, lest we be suspected of partiality, let us conclude with a sidelight on James I, to whom in a fulsome and naïvely blasphemous preface they dedicated that miracle of English Poetry, the Authorised Version of the Bible. Doctor Fian, or Cuningham, had been accused of witchcraft by an admitted witch who brought his name into a bawdy report. Being tortured by the

"boots" he signed a confession in the presence of the King (then James VI) and his Council. He was a very young man, and after escape and convalescence he openly repudiated the forced confession.

> "Wherevpon the kinges maiestie perceiuing his stubbovrne wilfvlnesse, conceiued and imagined that in the time of his absence hee had entered into newe conference and leagve with the deuill his master, and that hee had beene agayne newly marked".

(The devil's mark was a place that was not sensible to pain, and every accused witch was thrust with needles in every part of the body until such a place was found.)

> "For the which hee was narrowly searched, but it covlde not in anie wise bee fovnde, yet for more tryall of him to make him confesse, hee was commavnded to haue a most stravnge torment which was done in this manner following.
>
> His nailes vpon all his fingers were riuen and pvlled off with an instrvment called in Scottish a *Tvrkas,* which in England wee call a payre of pincers, and vnder eurie nayle there was thrvst in two needels ouer euen vp to the heads.
>
> Then was hee with all conuenient speed, by commavndement, conuaied againe to the torment of the bootes, wherein hee continved a long time, and did abide so many blowes in them, that his legges were crvshte and beaten togeather as small as might bee, and the bones and flesh so brvsed that the blovd and marrowe spovted forth in great abvndance, whereby they were made vnseruiceable for ever. And notwithstanding al these grieuous paines hee wovlde not confesse anie thing, so deepelie had the deuill entered into his heart, that hee vtterlie denied all that which hee had before auovched, and wovlde saie nothing therevnto bvt this, that what hee had done and saide before, was onely done and sayde for fear of paynes which hee had endvred.

> Vpon great consideration therefore taken by the King's Maiestie and his Covncil for the dve execvtion of ivstice vpon svch detestable malefactors, the sayde Doctor Fian was soone after araigned, condemned and adivdged by the law to die, and then to bee bvrned accordinge to the lawe of the lande, prouided in that behalfe. Wherevpon hee was pvt into a carte, and beeing first strangled, hee was immediately pvt into a great fire, being readie prouided for that pvrpose, and there bvrned in the Castle hill of Edenbrovgh on a saterdaie in the ende of Janvarie last past, 1591.

Sir Walter Scott in another narrative adds that Dr. Cuningham's fingers were mashed to pulp also.

§ 139.

One unpardonable offence of the witch was her knowledge of the harmlessness of those instruments of the Devil, the lizard, the grass-snake and the newt. She also somewhat affected the sacred beast of Bast, one of the goddesses fused later into the idea of Isis, and the possession of a domestic cat was dangerous. She was supposed to drown cats in wickerwork baskets when she desired to raise a storm, and innumerable aged women were burned to death in one year on this charge by the seasick King of Scots who became the first King of Great Britain. That desirable motion in the Air, of which we have written so much, was also, strangely enough, a possibility of witchcraft. Sailors, always the most superstitious of men, would buy wind, mainly in the Baltic and from Scandian or Finn sorcerers. The method is identical in Bartholomew, who wrote about 1250, and in the *Præceptorium* of Hollen, which appeared in 1481. It was the magic of Isis and Nephthys, involving a sack with three knots for the three intensities of wind, and the wind

was released, by sympathetic magic as if from the sack, just as Aeolus had released it of old from his hollow mountain with his whirling spear. To make hail, they were supposed to stir water in a hole.

That witches should move the Air did not surprise James at all. The Devil was the Prince of the power of the Air. If his characteristic rôle was reversed, that was characteristic of witchcraft. Witchcraft had always been antagonistic to the natural law and order of the World. "Fair is foul, and foul is fair". So in Apuleius, Meroë could turn the waters into hills and the hills into waters, and she could lift up the terrestrial spirits into the Air. Horace relates similar things of Canidia. Witches and evil spirits themselves, however, naturally fitted in the scheme of things. As light, flame and heat were associated with goodness, so darkness, mist and weight were associated with Evil and the Night. So also, again as in Mexico, where the dark demons were depicted as insects and the ash of vermin was a constituent of the witch-broth, worms and vermin hated the Light as vehemently as they loathed Salt, and, unless indeed the Church excommunicated them, they hid in the Earth. Excommunicated, however, with exemplary promptness and docility they died. Here is an example of the polarity associated with white and black, so common that we have not laboured it. Good spirits were the Shining Ones, and their priests wore White. We have it on the high authority of Athanasius that the Devil, in his actual, natural form, is a black child. He had aged by the time of Reginald Scot, but he had lost nothing of his blackness.

There might be a local Night or Heaviness within the human microcosm. "In the sweet Air made gladsome

by the Sun, carrying a foul and lazy mist within" as Dante writes—though Catullus calls it a Lethargy and identifies it with the Plague—and we have already seen that he regarded Darkness as a precipitation; even in twilight, the Air was "embrowned with shadows". For many centuries, Europeans of our era believed in this palpable blackness, and among the Romans of older days it was consciously from this blackness that they washed themselves in their morning ablutions. Night air is even still regarded as harmful. So muddled was medieval thought that the rich built their houses over wells—the living water—so that they might not take the plague from water that was stagnant or accessible to poisoners. Yet they could not thus escape the dampness which was really what they were seeking to avoid. After sunset the vapours rising into a now cooler atmosphere become visible. This was the earthy principle of evil mobility employing the chariot of Water; it was assisted by the attraction of evil by the evil mists of the Moon. In the modern city, to a nightworker returning home just before dawn, the most striking thing in the streets is the series of columns of mist, rising from the drains. These were the hags of hell. That is Shakespeare. He says:

> And now loud-howling wolves arouse the jades
> That drag the tragic melancholy Night;
> Who, with their drowsy, slow and flagging wings,
> Clip dead men's graves, and from their misty jaws
> Breathe foul, contagious Darkness in the Air.

So in the Arab night, "the Efriteh", a positive darkness, "ascended out of the well".

Readers of Jewish literature will recognise a familiar association of mist with darkness. Darkness was the

type or shadow of Death. Pestilence walked in darkness. Dark places were full of cruelty. The idea of a thick positive darkness is not only Egyptian but proverbially Egyptian; and the terror in darkness, the nightmare "horror" of darkness—which indeed might be a manifestation of Deity—is also Hebraic. One extant survival of the idea may be seen in the strikingly eloquent Stoic document called the *Second Epistle of Peter*. This speaks of "the mist of darkness" with a precise definition that is often lacking in the scores of other "canonical" passages that tacitly assume the idea. The creation of the subtle Light and the gross Darkness was a divine creation. Their separation was an act of God. Their source lay then somehow in the firmament and was thus a function of the stars. "It is not by any means the departure of the Sun that causes Night", says Paracelsus, "it is the peculiar nature of certain stars to produce Darkness, and it is so gross that unless the Moon interfered, nothing whatever would be visible". That was the general belief. Light was a genial balsam flowing to us from the heavens. Darkness was its polar opposite. As it came, the light appeared to "thicken". Because the Moon ruled the Night, it was recalled that the spirit of the Moon was of a moist nature and therefore attracted the marrow of animals—hence the miner's objection to washing his spine—as well as the tidal hump of the Sea. From another point of view the corpse-grease or witch-butter was fuel, but it burned with a blue flame, as in the thief's *hand of glory*, and in this instance the association is with Water and the Moon. It was fire but cold, blue fire like the brush discharge of Helen ("St. Elmo"), or of Castor and Pollux, upon the

masts of ships. One of the jests of Cyrano was that after he had rubbed himself with marrow he was drawn up to the Moon. It was a common saying and a world-wide belief that there was no wizard but had commerce with the Moon. The light of the Moon even resuscitated the slain Vampire: evil fecundating and attracting evil, even evil Fire. In older days, and in the South, when the Moon was still almost uniformly benevolent, Apuleius wrote that the Moon-goddess had "power to stop and repel the invasion of the hags and ghosts which appear unto man, and to keep them down in the enclosures of the Earth"—an actual repulsion like that associated medievally with the Sun—but even then she was feminine, for Dianus, who became Janus, was Chaos or the Sun.

Alas for Cynthia! There was no association now of a golden crescent with the Unicorn's horn which the proper officer still poked into my lord's dishes before my lord might eat. She was the watery star. Only of all that beauty, there remained the fetish of the Horse's shoe, and it has even been asserted that this was a magic of iron alone like the bars which Pepys records were laid across the beer-barrel. Why then its shape? When in England it took the place of the rowan-branch in the churn to burn the entrails of the ill-wisher who had bewitched the milk, why would not any piece of iron avail? The fact is that when the Turk inherited this Greek emblem, it became the device of Mahoun.

But if the Moon were evil, then Water was evil, and this aspect is fully developed in those Church myths that assign to Water the duty of domiciling the demons. Poor Neptune! O neglected Naiads! "Do not", asks Tertullian, "Do not the wicked spirits live in the waters,

in imitation of the act accomplished by the Divine Spirit at the beginning of the World?"—for it was axiomatic to the Churchman's mentality that the Devil was God's Ape. So in the *Miraculorum* of Cæsarius of Heisterbach, a monk of the thirteenth century, we are told how a priest named Arnold made his daughter cross the Rhine in the hope that the water would draw from her the demon with which it was supposed she was possessed. It was more customary to banish these possessive demons to the Red Sea. Luther knew of at least one dewpond that was full of demons, however; and in Pilate's Pool, the Devil himself took up his abode, indulging in the most infamous practices!

The emergence of terrestrial spirits into the Air, and the low flight of witches—similar to that of bats and butterflies, themselves often regarded as ghosts—was made more credible by the insistence that they were hollow. That was easy to believe for men who recognised elves that were living masks only, and so we find also in Cæsarius that the incubus demons were quite hollow, open at the back. This of course made it easy for them to dissolve and vanish. It also enabled Shakespeare to paraphrase the tedious expression "corporeal envelope" into:

> *Banquo:* The Earth hath bubbles as the Water hath
> And these are of them: whither are they vanish'd?
> *Macbeth:* Into the Air, and what seem'd corporal melted
> As breath into the wind.

Plutarch speaks of the "space where the phantom had been", but James denies any occupancy of volume to spirits. Be that as it may, a material envelope, in Origen's view, was essential to all spirits. Only the Trinity might

keep their individualism without some delimiting veil. Lesser spirits were in danger of mingling. Solid matter, therefore, had been produced—though not until the fall of the wicked angels—in order to receive them within its imprisoning boundaries, but it was itself, he adds, only a transformation of a subtle Light and Shining Matter which existed in the beginning. The bursting of these Earth-bubbles was one effect of Morning.

The medieval mind naturally had similar ideas about spirits that were not evil. Of Nicolette, the shepherds said "A girl came by, the loveliest thing in all the World. She brimmed our wood with light. We took her for a fay". Sometimes, as in *The Comedy of Errors,* there were reminiscences of the Roman tutelary genius or of the Egyptian Ka. There was nothing, as we have seen, that would distinguish them from human beings: "I think he be a spirit!": except their disappearance. So Prospero, having provided a wedding masque, says that the actors were all spirits, and have "melted into Air, into thin Air". After all, it was only three centuries at the most before Shakespeare that it was believed that the heliotrope or the recipe of fern-seed made men themselves invisible; and much later men accepted without question the opinion of the "Fathers" that Eve conversed with a spirit for whom the serpent merely provided an envelope.

§ 140.

If such ideas as these had their sources in ancient religions, they had also their counterparts in ancient philosophy; though naturally the cultivated and original thinker of one Age may be greatly in advance of an average non-thinker who flourishes some two thousand

years later. Ancient philosophy supposed that the immortal human soul was composed of particles of the Four Elements. Among the Epicureans the only essential difference was that the soul was mortal. On death, the soul left the body through the mouth or from a wound and fled to its abode; unless it was mortal, in which event it mingled with the Air, "as smoke mingles". Just so the life of Dido and of many other characters in the *Aeneid*, "vanished into Air". The gods did so too. It was an ancient jest that the particulate constitution of the immortal soul must suffer serious damage in a high wind. Primitive Man heard in its whistles and sighs the spirits of the dead. The abode of the departed intelligence has been assigned to each of all the four elements, and among some Mexican races, even to the Moon. A busy English journalist in the nineteenth century allotted the wicked spirits to the interior of the Sun. More graciously, among the Ancient Egyptians, it followed the boat of Ra through the Western Gate to a sorting-house in the Rice-fields of the Underworld. Here too reigned the Assyrian Ishtar, the Indian Bali, the Mexican Cinteotl, the Greek Pluto; here Hela dwelt at the roots of Yggdrasil with, indeed, all other earth-gods and gods of the dead. Hither descended the ghost of Homer's Patroclos and Dante in his own person. The Zulu can show the traveller the actual local entrances to this abode. The Mexican catacombs of Liyobaa were thought by the Roman Church's invaders to be the "backdoor of Hell". In many countries are legends of the disappearance underground of some old hero or even of some old race—Arthur, Charlemagne, Barbarossa, the Toltecs. With the Essenes and the Moslems, the soul, liberated from its

sordid prison, returned to the Empyrean, its first home. In medieval Europe, it might enter the gross central fire or thick-ribbed ice of the Earth, like Hamlet's father or like Ixion—bound with serpents to an unresting wheel—or in Dante's purgatory it might "dwell content in Fire" less corrosive, or it might melt into the Air like Hermione or Creusa or the murdered princes, "resembling most a fleeting dream" says Virgil; and Shakespeare says:

> If yet your gentle souls fly in the Air
> And be not fixed in doom perpetual.

Shakespeare's Petruchio says "Fear boys with bugs!", but the evidence of Sir Thomas Browne was yet to prove decisive against a victim of the scare of witchcraft.

Until quite recently, Breton peasants saw departed spirits in the spindrift and spray of the storm. Glendower believed in them, but Hotspur didn't. There has always been a belief, quite general, that the ultimate dwelling would be in the Heaven, and the primitive custom of burying fire-making materials with the corpse may have been the seed from which developed the later ritual of protecting it with candles and certain woods—fruiting woods were lucky as opposed to the wood of barren trees—from the spirits of evil who wished to drag the freed soul down to their own place. An instance of this malevolence is given in the *Book of Enoch* where the angels who, in the genesis of things, loved the daughters of man are represented as chained beneath the hills until the Day of Judgement. Then they are to be hurled into the abyss. But their hybrid children live in the Earth and ever attempt to injure the kindred of their Mothers.

Let us for refreshment see the views of Cicero and of Virgil. Cicero says:

"What evil has death brought? Unless perchance we are influenced by fables and nonsense to think that he is enduring in the shades below the punishments of the wicked and that he has met with more enemies there than he left behind here; and that he has been driven headlong into the district and habitation of wicked spirits by the avenging furies. . . . But if these stories are false, as all men are well aware that they are, what else has death taken from him except the sense of his misery "

Virgil says:

"The Deity pervades the whole Earth, the tracts of Sea, the depths of Heaven. From Him the flocks, the herds, mankind and all the beasts at birth derived their tenuous lives. Accordingly they all return upon their dissolution; they are brought back thither; nor is there any room for Death; but they mount up alive each to his proper order of star, and they take their seats in the high Heaven".

§ 141.

The hollow images of witches, dreams and spirits with which the Air was peopled did however receive a powerful reinforcement from the Epicureans, for in this philosophy sight was explained by a continuous sloughing of surfaces from visual objects. Other systems also contributed sight-entities to the aërial population. In the Chinese classic *Shan hai King,* so old that the snake still denotes Fire, there is a serpent god, "Enlightener of the Darkness", who "by opening his eyes creates daylight, and by closing them he creates night". He was red, of course. In Egyptian mythology, as we have seen, optical rays issued from the eye, an idea fortified by the consciousness of will in "looking" and "casting glances". This explained sight to the Stoics, to Boethius, to Montaigne, and, apparently, even to Dumas. Plutarch seems to have had

views which, save in this respect, were almost modern on the subject. He speaks of inflamed eyes as being hurt of brilliance of light, and comforted by dusky places and dark colours : "We tell people who are troubled with sore eyes to withdraw their sight from bright and offensive colours to green and those of a softer mixture". Yet the modern view does not account for the phenomena of mesmerism. Plato, followed by Ptolemy, believed that sight was due to the union of sight-rays with image-rays, an idea we have already explored. These three views, sight subjective, sight objective, and sight by union, jostled together into such theories as those of the cockatrice and of the evil eye; for the ray from the seer might be maleficent or the sight-ray in its return might poison its source, as when one beheld a medusa or a basilisk or an optically poisoned picture—the latter being an idea exploited by Shakespeare (?) in *Arden of Feversham*.

The ray might also have a healing or generative virtue, as the Sun's had. So the little masks of Bacchus hung in Roman vineyards, their features supplying something that was wanting in the decapitated trunk that stood for the Garden God, fructified tree and shrub and plant and seed in whatever direction the wind turned them. It astonishes us that Pliny and Virgil believed in the impregnation of mares by the wind; but what shall we say of Montaigne who believed that ostriches and tortoises hatched their eggs "with their looks only"?

These were influences or dews as well as rays, and it is a commonplace of astrology that even the radiance of Heaven was polar, friendly like the Sun's or cruel like that of Saturn. It is interesting therefore to find in Mexican folk-lore a similar polarity even in the heavenly

Rain—good rain and bad rain—stored in four butts in the courtyard of Tlaloc, and emptied by his somewhat clumsy dwarves who lived in four chambers, squarely built about it. The African Bavili have male rain and female rain.

The brief flowering of philosophy in the thirteenth century which saw the work of Grosseteste and of his illustrious pupil, Roger Bacon (who re-introduced lenses and mirrors) produced little disturbance in the trend of current thought, and having been subdued as witchcraft, was submerged in the Black Death. We find Dante writing of the Sun as "weighing our vision down", thrusting it backward. These apart, the first glimmer of the truth was again Francis Bacon's, who, though he likened the pupil of the eye to a mirror, observes that "the species of visibles seem to be emissions of beams from the object seen, almost like odours, save that they are more incorporeal". Montaigne, his elder contemporary, mentions (as translated by Florio) that "The Sun's light is not of one continued piece, but it so uncessantly, and without intermission, doth cast so thick new raies, one in the neck of another upon us, that we cannot perceive the space between them". These rays of light and sight, then, were part of the enormous organised and unorganised congeries and systems of particles in the Air, until Hooke recognised them as a pulse in the ether and followed up this thought with such zeal as to reject Römer's recent computation of their speed, both because instantaneity seemed more credible, and because there seemed to be a possibility that light was deflected by the attraction of Jupiter and its satellites, the eclipses of which were essential to the method.

§ 142.

By analogy, the Air was also full of sounds. These also might be bent in their paths, thrown back along their journeys, or focussed as to their intensity. These also might carry life and death. The young of lions were born dead, but were awakened by the sound of their parents' roarings. The bells that, on the wine-cup, drove away spirits of evil, were, in other contexts, a powerful attraction to the bees. Harmonious sounds were "sweet airs" and associated with goodness. Here again there was an argument by symmetry and antithesis. Bacon called these "the species of audibles" and felt that they were incorporeal, but not so much so as light, and much less so than those immateriate virtues which, since we do not understand them even now, we explain by the words hypnotism and telepathy. He was indeed approaching something that he could not see, but he progressed far enough to distinguish smells, plague and the fumes of charcoal from these more subtle entities which yet inhabited—or at least traversed—the same medium.

There were words in the Air, not as sounds—for they soon lost that property—but as entities of breath; and they were characterised by the thoughts which engendered them. The pure fire of words used in prayer carried them upward. Thither also went sincere and just vows. Jests did not take that direction, and spells were so gross as to be almost a palpable powder. Lovers' Oaths, in the Greek "epigram"—it is almost too cheap a cynicism—never reached Heaven. The breath itself might be good and evil. Thus the breath of cattle—except, in clerical effusions, that of the goat—even so late as Evelyn, fertilised the ground, whereas the breath of

the cockatrice or basilisk was even fatal. Some writers, however, as we have seen—Paracelsus is one—attributed the malevolent agency of the basilisk to its eyes. Its slayer should protect himself with a complete suit of mirrors. The breath was in a very special manner linked with the life, as in our previous reference to Ezekiel, where breath from the four winds, compelled by adjuration, repeopled the valley of dry bones.

§ 143.

All these vapours, dews, dusts and powders, all these forms, influences, rays and tinctures, moved, in healthy air, towards their own place, according to the balance of their fire and their ballast. "This Air, look you", mourns Hamlet, "this most excellent canopy, this brave o'er-hanging firmament, this majestical roof fretted with golden fire, it appears no other thing to me than a foul and pestilent congregation of vapours". They fled, "hic et illuc circumvolitans, along and down the Air". Small wonder that the air of mountain-tops was good, and that fever lay in wait in the marshes and flat lands! "Cheese", wrote Paracelsus, "is the mystery of the worms that dwell in it", and Air was the dwelling-place not only of Man, but of Shades, Deathly and Evil, holding all the equipment of necromancy.

The way out of this mystery owed much to the Epicureans, to whose philosophy, on certain points, Boyle found himself much attracted. There is a paragraph in his works which is so similar to this from Lucretius as almost to rank as a translation; Lucretius writes:

> "The air is changed every hour in innumerable ways. For whatever is perpetually passing off from bodies is all

carried into the vast ocean of air; and unless it were to restore particles to those bodies and to recruit them as their substance passes away, all things would by this time have been dissolved and converted into air. Accordingly, it does not cease to be perpetually generated from bodies and perpetually to return to bodies".

Thus arose a conception of the atmosphere as containing a fundamental basis of a pure matter which was identical with that constituting the Empyrean. Following Plato, and ignoring the very different use of the word by Aristotle, they called this the Ether. The flux of particles was a sediment in this ether and consisted merely of "effluviums". Boyle wrote a monograph upon them. It fell also to Boyle to develop a criterion by which at last the palpable and substantial constituents of the atmosphere might be distinguished from the incorporeal and immateriate virtues. He found this criterion in that property which distinguished air from water. Air was compressible.

§ 144.

The use of compressed air for the actuation of mechanical devices goes back at least to Ctesibius of Alexandria, a contemporary of Archimedes. Bacon tried to compress water, and was much interested in finding that, apart from the momentary and impulsive compression which we call sound, this was impossible; his container was of lead, and he discovered that the force applied was actually driving water through the "pores" of the lead, so that the external surface of the vessel was bedewed with it. A percussive local compression of the air transmitted sound too, but air might also be retained in a state of compression. Bacon tested "the opinion of

the ancients that in such air the phenomenon of putrefaction was hindered"; "it sorted not", however, "for dry bladders will not blow, and new bladders rather further putrefaction". He recommends the use of a hogshead and a pair of bellows, "and in the instant that you withdraw the bellows, stop the hole close".

Local pressures began to be recognised in the atmosphere. There was the ancient bellows of the smith, and the still more ancient motion of the wind, now more and more to be recognised as a movement of the air under a gradient of pressure rather than as an astral issue from sedate cherubic faces set in order due among the signs of the firmament. The force of explosives began to be understood. Shakespeare calls it "an abundance of superfluous breath".

> "The powder in shot", says Bacon, "being dilated into such a flame as endureth not compression, moveth likewise in round (i.e., equally in all directions) the flame being in the nature of a liquid body, sometimes recoiling, sometimes breaking the piece, but generally discharging the bullet, because there it findeth easiest deliverance".

Bacon thus conceived air as elastic, for he continues:

> "This motion upon pressure and the reciprocal thereof, which is motion upon tensure, we use to call by one common name, motion of liberty; which is, when any body, being forced to a preternatural extent or dimension, delivereth and restoreth itself to the natural: as when a blown bladder, pressed, riseth again; or when leather or cloth, tentured, spring back. This motion upon pressure is excellently also demonstrated in sounds".

Boyle similarly explains the action of the wind-gun. "It is no wonder that the air should, by the motion of restitution expand itself till it hath recovered its more natural dimensions". No wonder, indeed, and our habits

of mind make it almost incredible that this explanation should have been challenged by Hobbes, who said that its force was due "to the violent motion the air is put into by the vehement impulses of the rammer or sucker".

§ 145.

Rarefaction proved an even more difficult subject: when a content of heat carried a fume upwards, it was not realised that the volume of the fume was increased, and that it was this increase in volume—not the urge of a sky-pilot—that really made it less dense and more ready to ascend. The idea of vacuum, the limit of rarefaction, was long thought under the persistent influence of Aristotle and his followers, to be a thing abhorrent to Nature. (The Cartesians rejected it also.) The Great World-Egg was full, they said, even as the egg of a hen was full: hence they were called Plenists. The Plenist difficulties in face of common facts are further illustrated by Hobbes' discussion of the action of the medieval watering-pot, which had one hole at the top and many at the base, for Hobbes was a violent Plenist, though he does not seem to fall into any other philosophical category. Hobbes explained the cessation of the streams on the stopping of the upper hole with the finger by saying "that the water cannot, by its natural endeavours to descend drive down the air below it, because there is no place for the air to go". It must either re-enter through the top of the pot, or thrust up through the water! Yet Lucretius, in his *De Rerum Natura,* had exhaustively discussed this point. The solution was in Void, and this was plain to all who were not muddled by the weighty orthodox prejudice against anything Epicurean.

§ 146.

So it was easy for the opposing Vacuists to explain why a long cylindrical vessel, its open end beneath the surface of quicksilver, when raised to a vertical position should refuse to contain a greater height than some thirty inches, yet leaving a space above the mercury column. This was the "famous experiment" of Evangelista Torricelli.

Both sides were puzzled when a Florentine pump-maker found that water would not rise in a pump to a height greater than some thirty-five feet. Then a number of persons—Pascal, Ball, Bereguardi, Perrier, Townley—carried Torricellian tubes up to great heights, all of them using hills for this purpose, except Bereguardi, who picturesquely employed the Leaning Tower at Pisa. They all found that the height of the mercury column diminished.

Boyle, revolving these things, came to this conclusion: "The atmosphere we live in is not (otherwise than comparatively to more ponderous bodies) light, but heavy". The mercury was supported in the tube at such a height that it balanced the downward pressure of the Air. The less the height of the atmosphere above a place, the less pressure must there be, and the better could elastic bodies "display" themselves. This was confirmed by Pascal's reascent of this hill in the company of a limp football, which gradually became taut, and by Townley's reascent of his hill with a Torricellian tube into which a little air had purposely been admitted, the air expanding in the tube just as it did in the football.

§ 147.

About this time, Boyle read a narrative by Schottus, a German priest, of how Otto Guericke, consul of Magdeburg, had made a suction-engine. It was a clumsy contrivance, necessitating the continual labour "of two strong men for divers hours". Pressing Guericke into his service as the colleague of Robert Hooke, Boyle shortly found himself the owner of a greatly improved model. Then began a formidable series of classical researches, planned and explained with the most exquisite clarity of reasoning, culminating in the renowned law which, seventeen years later, was rediscovered by the Abbé Mariotte, who in France is still occasionally claimed as its originator. This then was the difference between air and water (or, as we say, between gas and liquid) that the same quantity of air will—not *fill*, but—*occupy*, different volumes; and he is led thus to picture the ultimate particles of the atmosphere :

> "There is a spring or elastical power in the air we live in, by which *elater* or spring of the air, that which I mean is this; that our air either consists of, or at least abounds with, parts of such a nature, that in case they be bent or compressed by the weight of the incumbent part of the atmosphere, or by any other body, they do endeavour, as much as in them lieth, to free themselves from that pressure, by bearing against the contiguous bodies that keep them bent; and as soon as those bodies are removed, or reduced to give them way, by presently unbending and stretching out themselves either quite or so far forth as the contiguous bodies that resist them will permit, and thereby expanding the whole parcel of air these elastical bodies compose".

He continues:

> "by conceiving the air near the earth to be such a heap of little bodies, lying one upon another, as may be resembled to a fleece of wool, for this consists of many slender and flexible hairs, each of which may indeed, like a little spring, be still endeavouring to stretch itself out again".

He concludes:

> "This power of self-dilatation is somewhat more conspicuous in a dry spunge compressed, than in a fleece of wool. But the air is not, like a spunge, an entire body, but a number of slender and flexible bodies, loosely complicated, as the air itself seems to be".

In a later passage he writes:

> "We may well suppose that a column of air, of many miles in height" (Kepler had made it eight, Ricciolo fifty) "leaning upon some springy corpuscles of air here below may have weight enough to bend their little springs and keep them bent; as, if there were fleeces of wool piled up to a mountainous height upon one another, the hairs that compose the lowermost locks which support the rest would by the weight of all the wool above them be as strongly compressed as if a man should squeeze them together in his hands . . . so that we need not wonder that upon the taking off the incumbent air from any parcel of the atmosphere here below the corpuscles whereof that undermost air consists, should display themselves, and take up more room than before".

Boyles' "crucial experiment" showed that if the mercury column were surrounded by a space which was gradually evacuated the height of the column itself gradually reached zero.

§ 148.

Such was the praise genuinely due to Boyle's achievement, and so great the sycophantic adulation of the new society of savants and gentlemen—which included

the egregious Pepys and the adventurous Brouncker—that he was betrayed in his own essays into using the phrase "vacuum Boylianum". As to his opponents, the bludgeon attacks of Hobbes were met by Boyle with the most devastating ease and equanimity, though he occasionally permitted himself the urbane omission of an *e* from his antagonist's name, a process to which his assistant Hooke was also often subjected. Neither seems to have retorted in kind. One of the most mirthful incidents of this history is the attack of a monk, Franciscus Linus, who gravely advanced the hypothesis that the column of mercury was held up "by a certain internal cord" (*a funiculo quodam interno suspendi*). One wonders whether this cord were a living agent, or whether its conceiver were merely even a worse Latinist than at this time was usual. If the finger were used to close the upper end of the tube, this cord, he said, could actually be felt; the finger was sucked in by this invisible leech-like thing "whose upper end, being fastened to the finger, draws and fastens it after this manner into the tube". Boyle wrote a special treatise to refute this theory, chiefly, it seems probable, for the sake of putting this unauthorised person into his place.

§ 149.

It must be admitted, however, that Boyle's images of fleece and sponge seem gross and crude when compared with Descartes' contemporary explanation of the same facts, Descartes conceiving a molecule such as is employed in thermal discussions at the present day. Boyle himself was impressed by the conception and was "not willing to declare peremptorily against it":

"The air is nothing but a congeries or heap of small and (for the most part) flexible particles, of several sizes, and of all kinds of figures, which are raised by heat (especially that of the sun) into that fluid and subtle ethereal body that surrounds the earth, and by the restless agitation of that celestial matter, wherein those particles swim, are so whirled round, that each corpuscle endeavours to beat off all others from coming within the little sphere requisite to its motion about its own centre; and, in case any by intruding into that sphere shall oppose its free rotation to expel or drive it away; their elastical power is not made to depend upon their shape or structure, but upon the vehement agitation, and (as it were) brandishing motion, which they receive from the fluid aether that swiftly flows between them, and whirling about each of them (independently from the rest) not only keeps those slender aerial bodies separated and stretched out (at least, as far as the neighbouring ones will permit) which otherwise, by reason of their flexibleness and weight, would flag or curl; but also makes them hit against and knock away each other, and consequently require more room than that which, if they were compressed, they would take up".

§ 150.

Air, at all events, was now acknowledged an elastic fluid. A century later, Scheele was to announce that it was a mixture of two. Before this was possible, certain progress was necessary along chemical lines also, and an account of this progress will be attempted in the next chapter. It suffices here to say that Boyle found that there could be no life long sustained in his vacuum, that there could be no putrefaction, and that—except in the presence of a certain substance—there could be no flame. In all the enthusiasm of the new discoveries, he kept his integrity. He was not

> "sollicitous to ascribe and vindicate to the air so absolute and equal a necessity to the production and conservation of all flames as divers learned men have concluded from my former experiments. But I, that am content to be kind to the air, but not partial, shall not scruple to declare to you that as much as some may think me beholden to the air for any discoveries of itself it may have vouchsafed me; yet I think a natural, as well as a civil, historian, does, in his accounts of matters of fact, owe more to truth than to gratitude itself. And though, wherever the air can challenge a clear, or at least, a probable interest in a phaenomenon, I am not only disposed, but glad to do it right; yet I would not easily assert to it a larger jurisdiction than I find nature to have assigned to it".

As a gentleman, it was incumbent upon him to be kind also to nitre.

CHAPTER VIII.

THE BLOOD OF THE SALAMANDER AND THE PHILOSOPHER'S STONE.

The Begetter of Things is not the Earth, but the Revolving Year.—*qtd. Evelyn.*

Heaven is open! Earth is open! Heaven is pregnant with wine.
Beautiful is that which belongeth to the Year. Beautiful things belong to the Year.—*Pyramid Text of Pepi.*

She dreamed she saw her father high in Air, washed by great Jove, anointed by the Sun.—*Herodotus.*

This is the true and genuine Balsam, the Balsam of the Heavenly Stars . . . for a sperm falls from the Stars.
—*Paracelsus.*

Then in fertilising showers descends the Universal Parent. Then the rains will soak the soil and a subtle vapour penetrate it. Then will the plants take courage.—*Virgil.*

I am Shu (God of the Atmosphere). I draw air from the presence of the Light-god, from the uttermost limits of Heaven. I know the Light-god: his winds are in my body.—*Papyrus of Ani.*

A radiation that is completely independent of the Sun, one that comes to us practically uniformly from all portions of the celestial dome. The cosmic rays enter the earth's atmosphere as a practically pure photon beam.
—*Millikan,* Nature, Jan. 31, 1931; p. 169.

§ 151.

If the day-sky was the ancient clock, the night-sky was equally the ancient almanack. Certain stars were prominent in times of rain. There were the "rainy stars". Others presided over wind, and it was natural

to suppose that they were concerned in its generation. The changing sky revolved with the changing seasons. The sky created them. The Sky was the Year. It was the Year that drenched the Earth with its varied influence.

The general argument of this chapter is as follows: Air had always been accepted as necessary to fire and life, but at the end of the seventeenth century it was still worth while for Hooke—who never wilfully wasted a moment—to show that bellows supplied with spent air would not revive a fire. It began to be thought that the fire-reviving element was that astral or rather firmamental radiance, or influence, or balsam, which produced nitre from excrements. Then combustion was recognised as a phenomenon to which two agents contributed. Hooke identified the comburent as that which was present both in air and in nitre. Mayow confused its essential characteristic with Boyle's elasticity and thus misled his follower Hales who, without realizing what he had done, first actually collected oxygen. Priestley and Scheele also collected oxygen in the same manner, from nitre. The suggestion is made that this was a secret of the alchemists. They seem also to have known that a similar effect was produced by treating calces, particularly those of lead, a point on which Priestley was at first misled because he had been sold carbonate for oxide. Thus he produced what we call carbon dioxide from material he believed to be a calx of lead long before he collected oxygen from the calx of mercury.

The goal of a third route to the discovery of oxygen —its absorption from air—had long been implicit in an apprehension of Leonardo da Vinci.

Finally Cavendish imitated nature by producing nitre from air.

The production of oxygen was conceived

(1) —by Hales—as the "Fire" of nitre. (Bacon one hundred years before had merely called it the "notable quick and windy spirit" of nitre.) The "salt" of nitre, its calx or ash, proved to be a body such that by exposure to Air or to Aqua Fortis, Boyle was able to renovate it again to nitre.

(2) —by Priestley and by Scheele—as the "Salt" or "Ash" or "Calx" or "Vitriol" of Air! Whence Scheele called it Aer vitriolicus, and Priestley called it Dephlogisticated Air, which being interpreted is Air deprived of its Volatile Sulphur.

(3) —as the firmamental balsam—recognised

(*a*) by Evelyn, as the life of Sap, added to Earth through the Air, the Dew, the Snow, the Hail and the Rain

(*b*) by Shakespeare as "a sweet aspersion from the Heavens"

(*c*) by Willis as a *pabulum nitrosum*

(*d*) by Mead as a *pabulum vitæ*

(*e*) perhaps by Boyle, but if so mistakenly, as the principle of Urine that produced the Unburning Fire of his "Aerial Noctiluca"

(*f*) by the alchemists as the principle that produced from dung and excrement, the Salt of Salts, Nitre

(*g*) by Scheele, who therefore at first called it Fire-air

(*h*) in calces; first by Boyle, who regarded it as ponderable heat, "igneous particles"; later by Priestley who called it The Air in Calces, and also "Fixed Air", a name later to be monopolised by the Air in Carbonates.

§ 152.

Only to the sophisticated mind has there ever been any difficulty about the relation of air to fire and life. It was their medium, betraying their existence and activities. In the Egyptian *Book of the Dead,* we find that a supply of air is necessary even for that shadowy form of spirit life which mounts guard over the embalmed body within the tomb. We have seen how the Ancient Assyrians insisted on the necessity for a good draught in the furnace; and we may recall that the phrase "vital air" is hardly less frequent in Homer than in Virgil. Some of the earliest Egyptian records show smiths blowing their fires through clay-tipped reeds, and at some later, but still prehistoric, time, the primitive iron-smelters of Egypt and of India evolved the goatskin bellows or blow-bag. Bellows are mentioned in the *Rig-Veda,* and Jeremiah laments that "The bellows are burned, the lead is consumed, the founder melteth in vain"—an interesting gloss on the antiquity of the knowledge of litharge. In the *Iliad,* the Wind is the ally of fire in its struggles with water, and the West Indian negroes have the same myth. Among the Norse, Loki the fire-god was a son of the Wind-Giant.

The wind entered into the strategy of incendiarism with every historical army and was not neglected by the armies of romance. Herodotus describes how "a violent

wind carried the flames" from cornfields, set on fire by a punitive expedition, "against the temple of Minerva Assesia, which caught fire and was burned to the ground". Virgil relates some thrilling spectacle of his own experience to the burning of Priam's palace: "In a moment, the devouring conflagration is rolled up in sheets by the wind to the lofty roof; the flames mount above; the fiery whirlwind rages to the skies". Livy and Dio Cassius both narrate how Tarquinius Priscus, in a quarrel with the Sabines, destroyed their bridge at the confluence of the Tiber with the Anio by floating down burning wood on rafts on the wind side, so that the rafts locked, forming an obstruction, and the kindled timber burned the bridge.

Armies might be trapped in woods in the flattering notion that they were preparing an ambush, or they might flee to a wood for refuge; then their opponents, having surrounded the wood, celebrated a holocaust by firing it on the wind side. The wood was often sacred. Then the gods intervened. Polybius has many stories of how the besieged poured fire on the rams of their besetters, and how these in turn, protected by their siege-machines, would dig beneath the wall, underpinning it meanwhile with props, and then set fire to the props; and in all these and in many other types of fighting, the wind was the first consideration. Here is Thucydides on the investment of Platæa:

> "After this the Peloponnesians, finding that their engines effected nothing, and that their mound was met by the counter-work, concluded that their present means of offence were unequal to the taking of the city, and they prepared for its circumvallation. First, however, they determined to try the effects of fire and see whether they

could not, with the help of a wind, burn the town—for it was not a large one; indeed they thought of every expedient by which the place might be reduced without the expense of a blockade. They accordingly brought faggots of brushwood and threw them from the mound, first into the space between it and the wall; and this soon becoming full from the number of hands at work, they next heaped the faggots up as far into the town as they could reach from the top, and then lighted the wood by setting fire to it with sulphur and pitch. The consequence was a fire greater than any one had ever yet seen produced by human agency, though it could not of course be compared to the spontaneous conflagrations sometimes known to occur through the wind rubbing the branches of a mountain forest together. And this fire was not only remarkable for its magnitude but was also, at the end of so many perils, within an ace of proving fatal to the Platæans; a great part of the town became entirely inaccessible, and had a wind blown upon it, in accordance with the hopes of the enemy, nothing could have saved them. As it was, there is also a story of heavy rain and thunder having come on by which the fire was put out and the danger averted".

That was in 429 B.C.

Five years later, the Athenians had seized the sacred city of Delium, and being besieged there had even drunk in a secular manner of the sacred water. The point of this quotation is that the man-in-the-street has always understood quite well that the rôle of bellows is to produce a wind. The Bœotians:

"succeeded in taking the fort by means of an engine made in this way: they sawed in two and scooped out a great beam from end to end, and fitting it nicely together again like a pipe, hung by chains at one end a cauldron. Now the beam was plated with iron, and an iron tube joined it to the cauldron. They inserted huge bellows into the

outer end of the beam and blew with them. Now the blast was closely confined in its passage to the cauldron; and the cauldron, being full of lighted coals, sulphur and pitch, made a great blaze and set fire to the wall. The defenders could not hold it. They left it and fled. The fort was taken".

Such ruses were familiar on both sides in the Crusades, and Villehardouin's *Chronicle* relates the Greeks' employment of fire-ships. The progress of arts and crafts produced ever new intimations of the relation of Air to Fire. Theophrastus, who was the lieutenant of Aristotle in respect of Botany, and his successor at the Lyceum, describes the preparation of charcoal by the partial combustion of wood in earth-covered mounds; it was found to be essential that the fire should not be visible through the top. A similar process, with similar safeguards, for the manufacture of lamp-black (for pigments and inks), by burning resins in a defect of air, is found in Vitruvius.

There were speculative thinkers, also, to whom the rôle of air was plain as a result of their own prejudices and habits of thought. Diogenes of Apollonia, ruminating in his tub, accepted it as a corollary to the common Greek teaching (the Platonic and Elean excepted) that each aggregate of matter must perish to release the elements required for new combination; consciousness he said was only maintained by a constant inhalation of the vital air, in which all reason resided. This conclusion he applied not only to land animals but to fishes, which breathed the dissolved air in their own element. Though Anaxagoras was in agreement with these conclusions, Aristotle—after demonstrating that the whole internal economy of animals was such as to create and

moderate the vital heat—said that the cause of respiration must be sought elsewhere. Similarly, Harvey in our own era held that breathing was a device for the *cooling* of the blood:

> "Inspiration is a means by which the blood in its passage between the two ventricles of the heart is tempered by the cold of the ambient atmosphere, lest, getting heated and blown up with a kind of fermentation, like milk or honey set over the fire, it should so distend the lungs that the animal got suffocated".

§ 153.

Among early experimental philosophers there seems to have been a good deal of confused thought on the matter. Undoubtedly the importance of draught is fully recognised in Agricola's illustrations of his furnaces; but he was a "practical man", and we are speaking rather of the virtuosi of the laboratory. To some, the vents in a lamp were to facilitate the escape of the smoke, which was dimming its light; the furnace-door and the use of the bellows were to remove the ash, for "covered fire", as Shakespeare's Hero said, would "consume away in sighs"; the philosophical egg was hermetically sealed to prevent the escape of the spirits. To others—or to the same writer in another mood—this latter precaution was not solely to promote the reflux of the volatile matter, but also to preserve the compound from "the noxious influences of the air", and the coals of the furnace were stirred with an iron rod "that they might meet the air, and the heat be increased". But that is Paracelsus, and Paracelsus in the Fourth Book of his *Treatise of the Nature of Things* states the whole explanation categorically, clearly and in detail. Such workers would at least

have no insuperable intellectual difficulty about the blowing of smouldering tinder, or the similar kindling of a recently extinguished tallow-candle wick—a pretty reliable operation, evidently, from its importance as an essential stage-direction in Shadwell's *A True Widow,* first produced in 1679. Smokers of tobacco must surely have been led also to certain definite conclusions. "Basil Valentine" understood combustion up to this point; yet he says "A combustible substance cannot shield another substance from combustion". Even Edward Kelle can tell us (as a great secret!) that if the hot, luted vessel be broken, "a little above the bottom, the black earth will kindle of its own accord and calcine itself marvellously".

§ 154.

Old as was the recognised connection of air with fire and life, it can have been but little older than the recognition of the pleasant properties of saltpetre or nitre. This was known to be the end-product of Nature's own sewage system, whether in the vat of the alchemist or following the pious practice of *Deuteronomy* 23[13]. Dried dung has been used in treeless countries as a fuel: so the Bedouin Arab is indebted to his camel; so we read also of the prairie Indian's "bois de vache": but in more populous districts heaps of decaying matter would be left to rot, sometimes in a state of smouldering combustion as in the Hebrew Gehenna, but generally in a state of slow natural fermentation. The more exiguous the sanitary amenities of a race, the more familiar would they be with nitre. The change to nitre from dung was one of the healing and sanative activities of the "influence" with which the ovoid fiery firmament irradiated all that

was within it. This was above all the region of active purity, and its radiance received such names as "astral balsam". One variant of the Prometheus story is that he sealed some in a bottle and used it to vivify his man of clay. It came, however, from the whole shell of the World, being an idea older even than the seven planets of the Chaldeans (which included the Sun and the Moon). We know now that it was a perfectly true idea. To quote Millikan, "The cosmic rays have their origin not in the stars but rather in interstellar space. They are due to the building up in the depths of Space of the commoner heavy elements, which the spectroscopy of the heavens shows to be widely distributed through Space. Has not modern physics thrown the purely mechanistic view of the Universe, root and branch, out of its house?" Shakespeare calls them "a sweet aspersion" (that is, sprinkling) and refers to their beneficence to growth. So Virgil says that Morning "Sprinkles the Earth". A. E. Housman has said that, too. As to whether this influence was corporeal or immateriate, it must be remembered that it was Light, and therefore, even with Boyle, a real substance until he had proved the contrary. Also it was akin, though in every way opposed, to those plague-bringing mists and aërial powders which descended from Saturn in Aquarius or from Saturn in conjunction with Jupiter or with Mars, for it was cold Fire, like the fire of frost or the fire of camphor. "But man may tame it", said Paracelsus.

§ 155.

There was, as a general rule, no distinction between sodium and potassium or between ammonium and potassium nitrates, nor between these and calcium nitrate,

a concretion upon the walls of stables. Such a distinction is once made in Paracelsus, but only for the sake of mentioning an interesting oddity, and we need not observe any such distinctions in this essay. The earliest historians, geographers and technicians speak of vast alluvial deposits or efflorescences of this substance, but always in dry countries. It has been obtained in modern times and in many places by the lixiviation of the soil. It was used in early times for curing meat, and for cooking, and for making freezing mixtures which would produce artificial ice, but these uses are not important to the present chapter : it is of real importance that it was employed as a manure and in the uses of fire. Virgil says "I have seen many sowers artificially prepare their seeds, and steep them first in saltpetre and black lees of oil". Some savage genius found it assisted him in boring through wood, exactly as Blackmore's Jan Ridd bored through his desk at school with a "winky". Thus too it helped the people of the riverside to hollow a log lengthwise into a punt or dug-out (cf. § 152, Thucydides, however), and some have thought that it even enabled the early miller (who yet almost universally used the primitive stone mortar and pestle of the rudimentary quern) to hollow out a cavity from the heart of the trunk at the centre, to hold the grain. The village firemaker, whose morning duty it would be to rake together the embers and blow up the fire, soon discovered the labour-saving device of sprinkling the hot ashes with nitre. He would early observe the effect of fire on mixtures of nitre and charcoal dust. Chinese Fire, the invention of which was certainly prehistoric, was such a mixture to which the powder of pyrites had been added. The

explosive principle of gunpowder was known therefore in times too remote to trace it. Yet Thucydides, an eyewitness of the Peloponnesian War, never mentions it. The Greek Fire employed against Alexander in India, however, was a mixture of pitch, resin and sulphur to which the addition of nitre seems to have been occasional and optional. "Several inventions of fire, which they flung among them" were employed by Octavius in the sea fight at Actium. The fourth century A.D. saw prepared pyrotechnic displays in Rome. In the seventh century Greek Fire was used in the defence of Constantinople. In the ninth century we find Leo VI, Emperor of the East, employing incendiary rockets, not thrown by hand, but fired from fixed tubes.

§ 156.

These preparations were known to the earliest European alchemists. Roger Bacon was an authority on them. The *Liber Ignium* of Marcus Græcus is to a large extent transcribed in the *De Mirabilibus Mundi* of Albert de Groot. That Richard the King used Greek Fire on his galley at the siege of Acre in 1191 suggests that it was the Crusaders who learned this among many other things in the East which they introduced into Western Europe. De Joinville describes it as he saw it in 1248 :

> "The Saracens brought an engine called a petrary, and put Greek Fire into the sling of the engine. . . . The fashion of the Greek Fire was such that it came frontwise as large as a barrel of verjuice, and the tail of fire that issued from it was as large as a large lance. The noise it made in coming was like heaven's thunder. It had the seeming of a dragon flying through the air. It gave so great a light, because of the great foison of fire making the light, that one saw as clearly throughout the camp as if it had been day".

By Tudor times, the use of gunpowder for projecting missiles from cannon had become quite common, and the art of pyrotechnics received considerable encouragement from the numerous hosts and entertainers of Queen Elizabeth. Above all, nitre was a familar weapon of the medieval chemist, in whose mind it was associated with fire as naturally as air was. It was in a brazier containing sulphur and nitre that Paracelsus publicly burned the works of Galen and other ancient authorities at his debut as professor of Physics, Medicine and Surgery at the University of Basle. Writing of the central fire of the earth, Alexander Seton mentions, without any explanation or comment but as a recognised, essential constituent, "the central saltpetre". The astral balsam had been subacted into a more dense medium of which it was now by so much the most important ingredient that "this saltpetre itself was once air". For "Air may be fixed. Its purest substance is the vital spirit of all creatures. It is the life of all". But in what manner did the Air obtain this function? He replies: "The more abundantly the rays of the Sun descend, the greater is the quantity of saltpetre generated". He was developing, as we shall see, a half-apprehended riddle out of Paracelsus.

§ 157.

A conception like this could not quickly find favour with the complacent and humourless celebrities at Gresham College. After Pepys' accounts of the first four of this sequence of meetings, the fifth has something of the effect of an anticlimax:

> "15 Feb. 1665. It is a most acceptable thing to hear their discourse, and see their experiments; which were this day on fire, and how it goes out in a place where the ayre is

not free, and sooner out where the ayre is exhausted, which they showed by an engine on purpose. After this being done, they to the Crown Tavern.

15 March, 1665. Among other good discourse, there was tried the great poison of Macassa upon a dogg, but it had no effect all the time we sat there.

22 March, 1665. There did see a kitling killed almost quite, but that we could not quite kill her, with such a way: the ayre out of a receiver, wherein she was put, and then the ayre being let in upon her, revives her immediately— nay and this ayre is to be made by putting together a liquor and some body that ferments—the steam of that do do the work.

19th April, 1665. So to the Change, and thence to Trinity-house, . . . and we to Gresham College, where we saw some experiments upon a hen, a dog, and a cat.

22nd Jan. 1666. The first meeting of Gresham College since the plague. . . . What, among other fine discourse, pleased me most, was Sir G. Ent, about respiration; that it is not to this day known, or concluded on, among physicians, nor to be done either, how the action is managed by Nature, or for what use it is".

Pepys' assiduous attendances were not wasted, however: this simple soul who mistook his own cat for a spirit, who believed that frozen birds were revived by warmth and that the proper treatment for a half-drowned person was to turn him upside down and let the water run out, this creature of his time who could write, "I bless God I have never been in such good plight, but I am at a great loss to know whether it be my hare's foote, or taking every morning of a pill of turpentine", was very suitably to become the President of this mutual improvement and admiration society (immortalised by Dickens) in which, by men like Boyle and Evelyn, office

was disdained. Each of these in his turn came to the same conclusion as Seton, that there was a saline powder diffused in space, a tincture or spirit, since it had no form, and directive in so much as it was of the nature of light or pure Fire; a nitrous suspension which might be called not only an astral balsam but a celestial nitre.

§ 158.

In *Terra,* Evelyn speaks of the value of "impregnating rains and dews, cold and dry winters, with store of snow, which I reckon equal to the richest manures, impregnated as they are with celestial nitre". For dissolving chemical sprays, he says it is best to use the rains of the equinox, for

> "of all waters, that which descends from heaven we find to be the richest and properest in our work, as having been already meteorised and circulated in that great digestory, enriched and impregnated with astral influences from above at those propitious seasons; whence that saying *Annus fructificat, non Tellus* has just title to a truth we every year's revolution admire, when the sweet dews of spring and autumn (hitherto constipated by cold, or consumed with too much heat) begin to be loosened, or moderately condensed, by the more benign temper of the Air, impregnating the prepared Earth to receive the nitrous spirits descending with their balmy pearls".

Because plants breathe, not only must their roots be "ventilated", but they themselves cannot live, "deprived of that breath and vital balm, which no less contributes to their growth and nourishment than does the Earth itself with all our assistance". "So a flower grows", says Catullus; "the breezes freshen it, the Sun gives it strength, the shower nourishes it". It is the old marriage of Heaven and Earth. "All Strength", says Paracelsus,

"comes from the Air". "The sky has condensed", says Horace, "and showers and snow bring down the Atmosphere". "Thou art purified", says the Pyramid Text of Unas, "by the libations of the Stars".

These nitrous spirits—and we might expect it from their nature as rays—are to Evelyn only another manifestation of protean Fire, the fire in the Air, the warmth of the nest, male in their nature and differing from the internal sulphur of the Earth only in their origin and purity; there is no sense that one is the complement of the other; rather, one encourages the other, the effect being clearly due to "the perpetual commerce and benign influences" of the Air,

> "charged as it comes with those pregnant and subtle particles, which insinuating into the Earth's more steady and less volatile salts, and both together invading the sulphur (and freeing them from whatsoever they find contumacious) that intestine fermentation is begun and promoted, which derives life and growth and motion, to all that she produces. . . . By the Air, the most effete and elixiviated Mould comes to be repaired and is qualified to attract the prolific nitrous spirits (which not only disposes the Earth to this impregnating Magnetism but converts her more unactive fixed salts into quite another genius and nature) . . . and all this by a naked exposure to the Air alone, without which it produces nothing".

He says the use of nitre in artificial composts consists in its introduction of this airy balm into the soil:

> "The improvement of all the Earths and soils I have spoken of results from this salt or spirit (call it which you please) as from an indispensable principle in this vegetation, and perhaps the first rudiment of life in all things".

and adds:

> "I firmly believe that were saltpetre to be obtained in plenty, we should need but little other composts to

> meliorate our ground; since whether that which so fertilises it, by any mixture we can yet devise, effect it from any other cause, is greatly to be doubted".

In § 105 we found this airy balm as a necessary contribution to the generation of metals.

§ 159.

Boyle had no difficulty in accepting the idea of particles and effluvia in the atmosphere. He followed the traditional view that there were three great categories of them, those coming up out of the Earth, those descending from the heavens, and those loosened from the surfaces of bodies. He had no doubt that saline particles entered the atmosphere from liquids as well as from solids, and, with his usual value set on experimental proof, carried out a periodic examination of copper plates suspended over jars containing respectively salt, nitre, urine and soot. He saw no reason why particles in the atmosphere should not be separated in some way, not then devised, similar to the separation by crystallisation of solids (e.g., alum and nitre) from mixed solution. We do that nowadays, liquefying air and then allowing it to aerefy once more, gas by gas. It is the most common source of oxygen and of nitrogen.

Boyle was conscious, however, of an incongruity in this common talk of the benignancy of nitre with the experimental fact that when he heated nitre in a closed vessel, its action was extremely corrosive; how did it square, moreover, with the freezing properties of nitre, unless indeed perhaps this celestial balm were the cause of the coldness of winds? "I have not found", he says, "that those that build so much upon this volatile nitre

have made out by any competent experiment that there is such a volatile nitre abounding in the Air . . . which yet I am content to admit as an ingenious supposition, until something be offered that shall prove it to be true"; but he writes later that his experiments and meditations suggest "a great suspicion of some vital substance, diffused through the Air, whether it be a volatile nitre, or some yet anonimous substance, sydereal or subterranean, but not improbably of kin to that (i.e., nitre) which I lately noted to be so necessary to the maintenance of other flames". Later still it becomes evident that he had frankly adopted the idea, for in speaking of the great rate at which putrefaction might proceed in Egypt, he thinks it may be "imputed to the nitrous salt, with which the air of that country so much abounds".

He is deflected from the great discovery by the preconceived notion that nitre is inflammable and partly, it seems certain, by the fastidious care with which his experiments were performed. He always re-crystallised his nitre, and, however many retorts he might ruin, refused to comply with the common practice of mixing it with unknown material, such as bone-ash, sand, or brickdust; thus his experiments were fewer and less successful than otherwise they would have been. Often the coal was blown out of the vessel by the "puffing matter", the "inflammable and halituous particles", which "tossed back the coals", "some brisk and invisible substance". He was not too easily convinced of its inflammability: though, on red-hot coals, it yielded "a blue and halituous flame", he must have recalled his own exposure of Porta's mistake in regarding the flame of the lodestone on coal as the spirit of the magnet. Yet

sal ammoniac was not inflammable, and sal ammoniac dropped on to boiling nitre gave a flame just as if it had been sulphur. We can understand now that this flame was the flame of a mixture of ammonia and oxygen.

Are we indeed so certain that Boyle finally failed? He had almost lost his sight when it was discovered that numbers of his manuscripts were lost, and hardly had this tragedy been realised when many others of his papers were ruined by vitriol upset over the chest of drawers which contained them. Among the lost papers were *"Of Fire and Flame, of the Fuel of the Sun's Fire, the Mechanical Origin of Inflammability"*, *"An Historical Dialogue of Flame"* and the actual results of some work indexed in advance as *"To produce air out of gunpowder and other nitrous bodies"*. It must be said in fairness to others, however, that though Boyle had got so far as to write that Fire was a *state,* as wind is a state of Air, he showed in his signed works no inkling of the idea that in relation to fuel, air and nitre had severally the same complementary function. Had he not suffered from the ill-luck we have described, his primacy would only have related to the actual isolation of the celestial balsam. He does, as it is, speak of "the divisibleness of nitre into fixed and volatile parts" and he regenerates nitre from the fixed (fused) portion with aqua fortis or by exposure to air. What actually mattered, however, had already been reached as a climax of brilliant speculation, suitably enough by a prince of experimental method and artifice—Hooke. With our different background, we can only appreciate his triumph fully in the realisation that he was the only thinker of his time to achieve it.

§ 160.

A certain amount of progress in the right direction had been made by Seton, by Maier and by Norton. Seton, who has already been quoted, used also the expression "the vital element of congealed air", by congealed air meaning nitre. The expressions in Paracelsus are "an included air", "a spirit of Salt" (*Salt* being commonly used to mean nitre) and "a mobile air that penetrates all stones, all metals, and everything without exception". Like Seton, Maier, who notes that "without air, the fire soon goes out", calls the celestial nitre "the hidden food of life". Norton writes that "the miraculous increase of the spark depends on its being fed with plenty of combustible matter" but does not think that air is the favourite food of fire, though "the transparent splendour and beautiful colour" of the flame are due to air; the favourite food of fire is Earth, that is, nitre. Finally, an anonymous writer, Eirenæus Philalethes, who was not Vaughan and has never previously been even tentatively identified as Boyle, writes:

> "The truth is, there are only three elements. Fire I do not acknowledge as an element. The heat there is in things is the product either of light, or motion, or life, or alterative processes. Fire is a violent corruptive motion caused by the clashing of two principles. It is an operation of two other substances, not a substance in itself—a result of the active co-operation of a comburent and a combustible".

§ 161.

This last step, however, was not taken, or rather was not published, until, in 1665, Hooke published his *Micrographia,* containing the historic "Observation 16", in which air and nitre are bracketed as solvents, differently

diluted, of fuels. (The Paracelsian phrase was that "Solution of Heat" dissolved fuels.) The old likeness to the ocean is observed, and the new dualism of combustion is proclaimed. His statements may be summarised as follows:

1. Air is the universal dissolvent of inflammable bodies.
2. As in making many other solutions, the solute must commonly first be heated.
3. Heat is evolved in this action, just as when making many other solutions.
4. The reaction is so violent and intimate that pulses are communicated to the Aether. These constitute light.
5. The solvent is a substance "inherent and mixt with the Air, that is like, if not the very same, with that which is fixt in Salt-peter".
6. A certain portion of the combustible passes into the Air.
7. Other portions, temporarily uniting with the Air, are found solid, when cold, in the soot.
8. Other portions, not suffering combustion, are yet heated and rarefied and carried upward by the flame.
9. Other such are too sluggish and gross to be raised by heat. These are ash or alkali.
10. The proportion of this solvent is small in the Air as compared with the content of it in nitre. There is "much flegme mixt with the spirits". A small amount of air is thus quickly glutted, "and the body leaves to be dissolved and to shine, which is the indication of it", however high it may be heated; whereas when nitre is heated, the dissolvent particles become more abundant.
11. As in making other solutions, a violent and copious application even of a weak solvent greatly accelerates the action, so if Air be applied with a bellows, the solution is as fast and as violent as if nitre were employed.

12. There is "no such thing as an Element of Fire that should attract or draw up the flame, or towards which the flame should endeavour to ascend out of a desire or appetite of uniting with that as its Homogeneal primitive and generating Element; but that shining, transient body which we call Flame is nothing else but a mixture of Air and the volatil sulphureous parts of dissoluble or combustible bodies, which are acting upon each other whil'st they ascend. That is, flame seems to be a mixture of Air and the combustible volatil parts of any body, which parts the encompassing Air does dissolve or work upon, which action, as it does intend the heat of the aerial parts of the dissolvent, so does it thereby further rarifie those parts that are acting, or that are very neer them, whereby they growing much lighter then the heavy parts of that Menstruum that are more remote, are thereby protruded and driven upward; and this may be easily observed also in dissolutions made by any other menstruum, especially such as either create heat or bubbles".

§ 162.

The excitement with which this inspiration came to Hooke is plentifully demonstrated in a plethora of underscorings, most of which are rather impatient than logical; in turn, this excitement itself demonstrates the author's complete innocence of any slightest plagiarism. Some century and a half later, the general stream of science caught him up. Meanwhile, philosophy creaked and groaned on a turn-table. It was difficult to get rid of the old notions and to realise that this celestial balsam was neither a species of radiant heat nor an exotic fuel. Six years after the issue of *Micrographia,* Willis still named it the *pabulum nitrosum.*

Three years later still, 1674, an amazing pack of nonsense, divided into *Five Treatises,* was published by John Mayow. This man had every advantage: he was a student of the philosophy of Des Cartes, and he had read the works of Willis, of Boyle, and of Hooke: yet the smallest flight on his own account seems to involve him in delirious absurdities. To him the particles of the balsam were identified with the flexible active particles of Des Cartes, and their characteristics were their elasticity and their motion, in other words, their heat. He attributes therefore to the balsam, which he calls "igneous spirit of nitre", "nitro-aerial spirit" and "nitro-aerial particles", all the properties then associated with heat and fire. The food of fire and of life, they were also the cause of lightning, of the motion of animals, of the freezing of water, of the fusion of the sparks struck by flint from steel. Their operations were manifold: they were acid and corroded iron; they existed in all acid liquids; they were the cause of the spring of the Air; it was their presence in flame which purged the Air from miasma and pestilence; it was by their impulse that light was propagated. They cured rickets—an interesting correlation with an activity which we also assign to the heavenly radiance. They were, indeed, particles à tout faire, and it is not surprising that on one or two points Mayow got the right answer though by fallacious reasoning. Boyle thought he had proved that heat was ponderable and attached itself to heated metals; it was in the form of this nitro-aerial spirit, said Mayow, that heat acted thus. This palpable fluke has, among many historians, who have ignored Boyle's prior reference to "igneous particles", gained him great credit. There is no

English translation of Mayow, however, and the Latin, being very tedious, is probably read with a certain unconscious selectivity.

§ 163.

Fifty years later, we find Mayow's influence misdirecting the very ingenious researches of the notorious parson Hales, the first volume of whose *Statical Essays* received the imprimatur of Newton on Feb. 16, 1727. That he was old-fashioned is evident from his nomenclature: "As Air cannot produce fire without sulphur, so neither can sulphur burn without air". That he was totally guided by Mayow is clear from such statements as that "Fire is chiefly invigorated by the action and reaction of the acid sulphureous particles of the fuel, and the elastic ones which arise and enter the fire, either from the fuel, in which they abound, or from the circumambient air". Pompously he sneers at the "Supposed vivifying spirit of Air" and then proceeds unwittingly to be the first man in history to collect it: "From 211 grains, or half a cubick inch of *Nitre,* mixed with calx of bones, there arose 90 cubick inches of air, i.e., a quantity equal to 180 times its bulk; so the weight of air in any quantity of nitre is about 1/8 part". A reference to the end of Chapter IV will show that oxygen was again masquerading as the fire-ghost, this time as the Central Fire, or Band of Union, of nitre; and that was the only aspect of the matter in which Hales was interested.

§ 164.

"The cause of the death of animals in confined air is not owing to the want of any *pabulum vitæ,* which the

Air had been supposed to contain" writes parson Priestley, the second man in history to collect oxygen; but he was justified, having been defrauded in the chemicals supplied to him, as we shall see later. When he wrote this—it is a description, published in 1774, of work done "before 1772"—he had already collected it. In other ways, also, his work is reminiscent of Hales', whom he greatly admired, though he did not imitate the more incredible cruelties inflicted by Hales on highly sensitive animals. Hales, it will be remarked, speaks of "elastic particles" as coming out of the fuel: a passage of Franklin's letters quoted by Priestley states that "What escapes and is dissipated in the burning of bodies, beside Water and Earth, is generally the Air and Fire that before made parts of the solid".

§ 165.

The two theories were not regarded in all quarters as necessarily antagonistic. Mead, dealing with Plague and Venomous Exhalations, claims to have proved "that there is a vivifying matter from the Air, which passes into the blood by the breath". But, in relation to Sutton's invention for sucking air into the holds of ships by keeping hot a part of a system of pipes, he writes that "It is that property of the Air which is called its elasticity or springiness which makes it so useful to our life". It is not as though Mead had failed, like Harvey, to understand the use of air in breathing. Compare his views with a contemporary view like that of William Watson, who wrote in 1741:

> "A number of uncleanly people being stowed too close together heat the air and make it replete with noxious effluvia which destroy the particles therein adapted to cool

> the lungs, particularly the acid nitrous gas. This principle is abundant in cool air, and manifests itself not only from the quantity of nitrous crystallizations which may be collected from caverns of the earth, especially those open to a northerly aspect",

but from the change in the colour of butchers' meat.

> "Air robbed of this valuable property, and replete with hurtful ones, not only from the people, but from the stinking water in the well and lower parts of the ship, must produce the most putrid, if not pestilential fevers".

Whereas Mead writes:

> "I think it certain that respiration does always communicate to the blood some parts from the Air: which is proved from this observation, that the same quantity of air will not suffice long for breathing, *though it be deprived of none of those qualities by which it is fitted to inflate the lungs and agitate the blood, the uses commonly ascribed to it.*"

The words we have italicised show the supreme irrelevance of Mayow's reference to elasticity. It seems probable that Mead never read Hooke's speculations on combustion, his sole reference to Hooke in all his works being as follows: "The mechanism of the sting of a Bee, Dr. Hooke has very accurately described".

§ 166.

Priestley describes his collection of oxygen in the following words:

> "In one quantity of factitious air which I got from saltpetre a candle not only burned, but the flame was increased, and something was heard like a hissing, similar to the decrepitation of nitre in an open fire. This experiment was made when the air was fresh made, and while it probably contained some particles of nitre which would have been deposited afterwards. The air was extracted from these substances by heating them in a gun-barrel,

which was much corroded and soon spoiled by the experiment. What effect this circumstance may have had upon the air I have not considered. . . . This series of facts relating to air extracted from nitre appear to me to be very extraordinary and important, and, in able hands, may lead to considerable discoveries".

§ 167.

"Before 1773", Scheele independently made the same experiment. He had been boiling nitre in a crucible over an open fire, and he noted the intense radiance of the hot sparks carried across the mouth of the crucible as they ascended the chimney. He collected some of this "wind", as Paracelsus had called it. He named it "Fire-air" and identified it with the pure calms of the Empyrean. And this is pure Morien, for Morien had written of the Philosopher's Stone, "It dwelleth in the Air in the form of Fire".

§ 168.

Was then the preparation of oxygen from aërated dung one of the secrets of the alchemists, whose philosopher's stone was identified with Azoth and Alcazoth, the incubating fire of the Universe? What saith Seton?

"Air contains the hidden food of life, of which the invisible spirit, when congealed, is better than the whole world. The substance is vile and yet most precious. Subject it to coction until it becomes first Water and then something which is not Water. If you do not know how to do this, and how to cook Air, you will go wrong, for herein is the true Matter of the Philosophers. You must take that which is, but is not seen until the operator pleases. This is the Water of our Dew, which is extracted from the Saltpetre of the Sages, by which all things grow, exist

> and are nourished, whose womb is the centre of the celestial and terrestrial sun and moon. To speak more openly, it is our Magnet, which I have already called our Chalybs, or steel. Air generates this magnet. The magnet engenders, or manifests, our Air".

Paracelsus says that iron will burn "like straw". So it will—in oxygen. Diderich reports that a "fire-philosopher" recommended "bottled wind" as a cure for the plague. This mystical injunction was not understood, and it received a grotesque interpretation. But Wind was peculiarly rich in the nitrous exhalations, coming as it did from the "conflict of vapours" at the Cloud Level: for Cold was the parent of all winds, and the stars were its vials and cucurbits.

§ 169.

In spite of the history of the formation of nitre, the celestial balsam was regarded rather as its soul than as its spirit, but the activity of the soul was such as to arouse an expectation that the spirit would be acid. The radiance that glazed the snow and was itself congealed in nitre had effects of fermentation quite congruous with its nature as fire, and when matter fermented it was heating (like wine) or sour or acid (like vinegar). The first leaven was merely sour dough, but it was a fire good enough to use as a parable of the central soul in the microcosmic kingdom of heaven. The spirit of nitre, however, was that which was driven off by heating the crystalline body with the fixed, incombustible sulphur which was also called oil of vitriol. Surely this should be the soul; but no, for it was liquid.

This spirit of nitre was known in very ancient times as aqua fortis, and as a constituent of aqua regia or

aqua regis, that 'vinegar' with which rocks were made to crumble. It was another connection between nitre and air that "torn up by the roots", metals rusted in air and also produced calces under the action of the spirit of nitre. "The calcination of metals is not of a single kind only. It may be produced by strong waters". Boyle speaks of two cold bodies which, together, produce a flame. He may not have been the first to notice that this was the result of pouring aqua fortis on to dry sawdust. Moreover the distillation of aqua fortis which in any event was necessary in its preparation has a picturesqueness which must have been very striking to minds attributing the redness whether of apples or of red lead to the trapped sunlight that they hid. A red cloud rises, passes over into the receiver and settles as a colourless liquid. Now for many centuries it had been customary to speak of the cold of poison or venom as "The blood of the Viper", and so this red cloud, which is very rich in oxygen, was called by the alchemist "the blood of the salamander", that is to say the very being or life of the essential essence of fire.

§ 170.

It seems probable that the preparation of oxygen from the red oxides of lead was known also to the alchemists. Boyle burst a vessel containing them by heating it. Priestley collected gas thus evolved, but it was not "The Air in Calces"; he had unwittingly been heating a carbonate supplied to him as "Red Lead": the gas was what we call carbon dioxide. But we have already found litharge as a subject for the chagrins of Jeremiah. Here was an adorable paradox for the

alchemist, for lead was the metal of the injurious Saturn, a cold star, a star as malignant and evil in Augustan poetry as in Paracelsus. The author of *The Philosopher's Stone* says "Seek for the noble child where it lies in a despised form, shut up under the seal of Saturn", and although this interpretation is at first sight discouraged by other words of the same writer, where he says that "ores may, indeed, when they have been fluxed in the fire, contract a rust, which is a gradual decomposition of their substance", we must not assign him processes of thought congruous only with modern knowledge. It is far more important to note that Norton says in the *Crede Mihi, the Ordinal of Alchemy*, that that Earth which is the favourite food of fire "is the earthy litharge of our stone". "Of this earth Albertus Magnus says, that among all mineral substances litharge is the most suitable for our white Elixir". It is well-known that Albert de Groot (whose name was latinised in this flattering manner) utterly denied the power of alchemy to produce metallic gold. When Kelle writes: "The Water may be changed into Earth, and thus into our red, fixed powder, which, after fermentation, becomes our Stone", he may be translated as saying that mercury may be dissolved in aqua fortis, the resulting nitrate broken down to the oxide, "which on ignition yields oxygen".

§ 171.

At any rate, experimentation on the calces of metals was incontestably one road to the isolation of oxygen. In his book *On the Ills of Metals,* Paracelsus writes "The Sublimation of quicksilver has this operation, that even the Air in its vicinity has a recreative effect". The calx

of quicksilver was, in Boyle's time, the centre of especial interest, and it is instructive to see that he follows Paracelsus in associating the various "calcining" operations of the laboratory:

> ". . . as when iron or copper, by an acid menstruum, that corrodes and associates itself with it, is turned into vitriol of Mars or of Venus; and quicksilver, having a sufficient quantity of aqua fortis strongly abstracted from it, is changed into a red precipitate; or by being sublimed up with common sulphur is turned into cinnabar; or, to give yet a more apposite example, when quicksilver is, by the lasting operation of the fire, without external additaments, at least distinct from the igneous particles, turned into a red powder, that chymists call *Praecipitate per se*".

and again:

> "The bare accession of igneous particles is able in time to turn running mercury into that red powder which chymists call *Praecipitate per se*: and I have found by trials purposely made, and elsewhere related, that this powder without any further additament may be reduced into running mercury".

This of course, was the world-famous experiment of Priestley, one hundred and thirteen years later, but Priestley actually collected "these penetrating igneous particles, especially saline", as Boyle, in yet another reference, had called them. So far as we know, or shall ever know, Boyle did not.

§ 172.

Another line of research had been forecast, by Priestley "before 1772", and by Scheele "before 1773", which is indicated by the former as follows: "Common sulphur is as mild as air, though nothing can be more destructive than one of its constituent parts, oil of vitriol.

Common air, therefore, may be composed of similar principles, and may be a real sulphur". That is to say that as sulphur consisted of phlogiston and vitriol, so air might consist of phlogiston and (air minus phlogiston) or "dephlogisticated air", which was thus the first name assigned to what Lavoisier was later to call "the acid-forming principle", *le principe oxigine.* Independently following the same line of thought as Priestley, Scheele called it aer vitriolicus. The further line of research was the removal of this material from the Air. It was not a new experiment. Bacon tells us that it was a common amusement in his time to invert a glass over a lighted candle floating, on a cork, in a basin of water, the rise of the water being ascribed to "the drawing of heat". Bacon contests this. It is due, he says, to the decrease in size of the flame as the "close air" suffocates it.

> "The flame occupying less and less room, as it lesseneth, the water succeedeth. But upon the instant of the candle's going out, there is a sudden rise of a great deal of water; for that the body of the flame filleth no more place, and so the air and the water succeed".

The experiment, he says, may be performed over flour or sand, so that it cannot have anything to do with the drawing of moisture by heat.

If Leonardo da Vinci had lived a few years later, perhaps, when Western Europe was notoriously "aping the manners of proud Italy", Bacon might have heard of his acute conclusions about combustion, and the course of scientific history might have been cut along a much straighter line. This prodigious Italian had written :

> "The element Fire consumes continuously that portion of the air which nourishes it, and there would be formed a

> vacuum if other air did not come to supply its place. . . . When a flame occurs, there is started a current of air, generated thereby. This draught serves to maintain and to increase the flame. The fire destroys without intermission that air which supports it, and would produce a vacuum if other air could not come to supply it. So soon as the air is no longer in condition to sustain a flame, no earthly creature can live in it any more than the flame can".

But Leonardo was so far in advance of his time that his contribution to the truth was actually wasted; and the lesson behind Bacon's "common experiment"—the origin of which has actually been attributed to Mayow!—remained unlearned. In 1726, the publication of *The Voyage to Laputa* showed that learned men could still think it a joke to regard the air as a matter which might be condensed "into a dry tangible substance, by extracting the nitre and letting the aqueous or fluid particles percolate". In 1772, however, Rutherford prepared "mephitic air", absorbing the oxygen by respiration, and the carbon dioxide with lime; and Priestley prepared his "saturated air" or "phlogisticated air" by burning charcoal and absorbing the carbon dioxide with potash. Scheele carried out similar experiments, making "foul" or "corrupt" air, and it was Scheele who first stated that the atmosphere consisted (mainly) of two gases, this "nitrogen", as Chaptal called it, being one, and the "dephlogisticated air" being the other. Once more polarity had triumphed. Oxygen was the food of life. Nitrogen was *azote,* lifeless. The necessity of nitrogen to vegetable growth has thus no niche in our history.

§ 173.

It was by the synthesis of water, however, and not by the analysis of air, that the phlogiston theory was dismissed. Kirwan stated that hydrogen was phlogiston, and both Cavendish and Priestley thought that at any rate it was very rich in phlogiston. Priestley, therefore, conceived the idea of heating calces (that is, dephlogisticated metals) in the presence of hydrogen. He obtained water. He obtained water also when he allowed an electric spark to pass in a vessel containing a mixture of hydrogen and air. In 1781, Cavendish discovered that a mixture of two volumes of hydrogen with one of oxygen combined together to form water equal in weight to its constituents. So that "the inflammable air from metals", "the volatile sulphur of the Mars", did not come from the metals: it came from the water of the acid. Lavoisier added further proof by weighing metals and their calces, the increased weight coming out of the Air, "subacted", as Bacon had forecast, "into a denser medium".

§ 174.

Cavendish made the final contribution which the symmetry of events in this history requires. "Canst thou bind the sweet influence of the Pleiades?" asks Job. In his letter to Campi of 8 May, 1777, Volta—who, in Chemistry, was an admiring follower of Priestley—mentions that the explosion of some (air-diluted) electrolytic gas in his hand-gun produced some acid. He attributed this to an acidifying principle in the inflammable air. But at this period of the evolution of chemistry the important point was not the rôle of hydrogen in the

formation of acids nor even the fixation of atmospheric nitrogen: it was the power to give at last an affirmative answer to a question that Priestley and Hales at least may be presumed to have read: Canst thou bind the sweet influences of the seven daughters of the Atmosphere? Volta could not say Yes: he did not know what he had done, but Cavendish, in 1781, by sparking air over a solution of ash, produced nitre.

CHAPTER IX.

MR. PICKWICK AND NEIGHBOUR SEA-COLE.

Come hither, neighbour Sea-Cole. God hath blessed you with a good name: therefore bear you the lantern.
—*Shakespeare's Dogberry.*

§ 175.

We come now to the old association of the polar pairs Light and Darkness, Joy and Grief. From the ancient camp-fire or nobleman's hall or village-hearth to the brilliant street of the modern city, the intrusion of light on the season proper to darkness has exercised an unbroken fascination. In this there seems to be present, besides the normal instinct for cheerfulness, an odd element of that attractiveness which is associated with the extravagant and the barely permitted, perhaps even with the joy of defiance of the celestial arrangements—or the arrangements of municipal committees—for our tutelage and good government. Consider how a single torch, under Solon, preceded the chariot of the modest woman who was abroad after nightfall; and how, under Lycurgus, men were forbidden chariot and torch alike as enervating luxuries. It must be admitted that later, in Roman days, the torch-bearer of the nobilis was the first mark of the thief or assassin, and held thus an ungrateful office in unsettled times; yet to speak more generally, the use of light, when the face of heaven was dark, was an act akin to making the fountains run with wine. It was

festal: "Rejoice with me, for I have found that which was lost": and so when Perdita is found again, Shakespeare exclaims "Nothing but bonfires!"

With armies, extravagance is normal; but save among armies on active service, where there was a set time for kindling the lamps, the early public lighting was limited to public festivals, the Chinese "Feast of Lanterns", the Jewish "Dedication of the Temple", or the Egyptian celebration of the day of Minerva of Sais, the "Lychnocaia"; and these were genuine public festivals, to which each individual contributed by burning a lamp outside his house all night long. Spontaneous outbursts of joy on the successful protection of the public safety were marked in the same way, as when Cicero defeated the conspiracy of Catiline. "A bright light shone through the streets from the lamps and torches set up at the doors, and the women showed lights from the tops of the houses". Bonfires and avenues of lighted torches flattered the approach of the despotic monarch. Processions with cressets swinging from forked sticks greeted the honoured guests of Prester John. Antony "found Cleopatra's preparation to receive him magnificent beyond expression, but nothing so admirable as the great number of lights; for on a sudden there was let down altogether so great a number of branches with lights in them so ingeniously disposed, some in squares, and some in circles, that the whole thing was a spectacle that has seldom been equalled for beauty". Similarly, the private jubilations of wedding and birth were occasions for light.

On the other hand, what Harpagon termed "thrift" has always made a special interest in private lighting. Whether because extravagance and the normal are

naturally opposed or because, while diet can be varied and clothes may be made to last a little longer, the consumption of fuel is inevitable and inexorable, excessive illumination always invites censure. On finding a light burning in an empty room, the small householder immediately becomes the heavy tragedian, and, in the latter years of the nineteenth century, he would herd his entire family into one chamber for the evening, see that they all retired before him, turn off the gas at the mains and then march responsibly to bed himself, Malvolio, majestic with his candle. Had he but known it, he had many classical sanctions. Demosthenes himself was rebuked for working by candle light, but he retorted that darkness suited thieves, an aphorism echoed in the New Testament. Told that his arguments smelt of the lamp, he replied "Your lamp and mine, Pytheas, are conscious of different things", a metaphor more explicitly expressed by Bacon's now familiar description of the intelligence as "a kind of flame". Tiberius Gracchus was "upbraided that when his father was Censor, the Romans, whenever he happened to be going home from a supper, used to put out all their lights, lest they should seem to have indulged themselves in feasting and drinking at unreasonable hours, whereas now the most indigent and audacious of the people were found with their torches at night, following Tiberius home". Light appears in the indictment of Timon's extravagance:

> When all our offices have been oppressed
> With riotous feeders, when our vaults have wept
> With drunken spilth of wine, when every room
> Hath blazed with lights and brayed with minstrelsy.

So Leonato speaks contemptuously of drunken "candle-wasters". So Banquo says of a dark night "There's husbandry in heaven, Their candles are all out", and Hamlet calls the sparkling firmament "brave", as one might speak of a new cape and sword. Bacon charges the sea-coal men with mixing dirt in the authentic fuel, and Pepys notes in his diary the price of the same commodity, on 7th March, 1667, exclaiming "This day was reckoned by all people the coldest day that ever was remembered in England; and, God knows! coals at a very great price".

Similarly, darkness and gloom were appropriate to grief, a kindred association which persists. Hence, even in England in the twentieth century, windows are *blinded* for death in the house of a neighbour, a gesture whose original poetry has been stifled by what "Q" has called "Kumeelfo" and an artless reverence for form. In olden times, men covered their heads, for their eyes, also, as we have seen, were regarded as windows of issue. There is a sharply edged contrast in a vision of Esdras where, in lamenting that her only son died during the festivities of his own wedding, a woman says "Then we overthrew all the lamps". As with bells, the beacon might, it is true, be used as an urgent summons in time of danger, but the first association, both of carillon and bonfire, was joy.

§ 176.

Private interest led to the exhibition of lamps outside baths, taverns and brothels. The sign of the individual inn was more or less superfluous; what mattered was the bush—which signified warmth and fuel—and the lantern, which stood for good cheer. Shakespeare is never weary

of likening the front of the inn to Bardolph's face, where he had hung out a lantern before him, and, no doubt, grew a bush also. As the corporate consciousness that preserved a camp-fire or prytaneum developed into highly organised local government, there was more and more lighting of the streets. It is recorded that towards the end of the fourth century the streets of Antioch were regularly illuminated every evening. In the beginning of the sixth century, the same thing was true of Edessa. After the peak of civilisation had moved, very slowly, westwards, there are records of the increase of public illumination in Paris. In 1524, the inhabitants were ordered to keep lights burning after nine in the evening in front of all windows facing the street. This light was reinforced, in 1558, by that of large urns, filled with pitch, resin, and other combustibles, which were placed at least at the corner of every street. These "falots", as they were called, had already been employed for lighting the courts of the great palaces, but, now that their number was so greatly increased, their inconveniences became apparent, and they were soon superseded by lanterns.

Similar progress took place in London, for we find that about a century later the inhabitants were admonished that they should hang out lanterns duly at the accustomed time—but when this observance started is not known. The light was to be maintained from dusk to midnight between Michaelmas and Lady Day. The business passed into the hands of private contractors, and was attended to so ill that in 1736 the city acquired statutory authority for municipal lighting with glass-covered oil-lamps from sunset to sunrise throughout the

year. Londoners were very proud of this achievement. They calculated in 1786 that Oxford Street alone contained more lamps than all Paris. "The lamps, where a great many roads cross each other", says Beckmann, "have a beautiful and noble effect". By this time, Rome was the most considerable European city still unlighted, but Sixtus V, who was in favour of lighting, achieved his purpose to some extent by increasing the lights placed before the images of the saints.

§ 177.

The growth of the lamp from the first oil-dip or night-light is an evolution readily understood. Neither is mentioned in Homer, where illumination is increased by throwing pine-torches on to the hearth; for pine was a smoky wood, full of resin, useful for making pitch, and hence it gave a flame brighter than that from other timber. Yet lamps are familiar in the pyramid texts of the Fifth Dynasty, and Virgil employs them in his description of the Trojan days when "down from the gold-fretted ceiling hang the flaming lamps, and torches overpower the darkness of the night". The hanging lamp started new trains of thought, if, as it is said, the great hanging lamp in the Cathedral at Pisa led Galileo to considerations about the pendulum. The brass stand-lamp is still common with us, though under sentence of extinction by electricity, but one does not often now see, hanging to it by a chain, that instrument whose name so appealed to Dickens, the "pickwick".

The evolution of the candle from the torch or fire-brand is fuller of incident, though the main lines of growth are again quite clear. Virgil's farmers whittled

torches in the winter evenings to the sound of the good wife's song and shuttle, but even in the time of Tutankhamen, the torch-substitute had started its career; for in his tomb were found not only the rods of pitch-pine, but bodies of birds, threaded with cane or rush. It was discovered that many objects were entirely satisfactory as torches if they were first steeped in tar or in fat. Thus rushes, peeled and dried, and twice or thrice immersed in fat, produced the rush-light. By the beginning of our era, there were not only the lampas and the fax, which were definitely torches, but the candela, which was a taper or cord preserved in wax, and the funale, a name suggesting something much stouter. Apuleius mentions the sebaceus, or tallow-candle, which really was a candle, since the most important thing about it was the sebum or grease. These were long an article of domestic manufacture, so that many centuries later Ethelred the Unrede was flogged with them, an indignity which Odysseus came near suffering with torches. Knight mentions, as an example of the prosperity of the English farmer in the sixteenth century that "he sawed out his own timber. He made his own candles and his own charcoal". These candles were enormous things. Shakespeare's swaggerer Petruchio is made to use two of their casings as a pair of boots. Even the wax "tapers" carried by penitents weighed normally two pounds apiece.

The author of the early English prose romance *Virgilius* records a curious class distinction which appertained to the torch and the candle: on an occasion when "Virgilius" had magically extinguished all fire in Rome, his wrath being after a time assuaged, all the city came to the market-place; "there men fetcht fyer: the pore

men with candels and strawe, and the ryche men lyghted they theyr torches". It was very little later, however, that the nobility and gentry of London were buying candles from a wax-chandler of Lambeth Marsh, whose name was Thomas Field. One of the changes at Tom Killigrew's theatre, after the Great Fire of London, was that instead of a bare three pounds of tallow-candles, numerous wax candles were used, this being regarded as an enormous improvement in the amenities of the place; a contemporary change was the ceasing to cover the filth upon the floor with rushes. (Even at this time there might be emergencies leading to the use of the simple firebrand, as when Pepys, wakened by chimney-sweepers in the night, put on gown and breeches and suspected burglars.) So late as Thackeray however we still find "waxlights" and tallow-candles as infallible indications of wealth or of poverty. Tallow-candles are seldom seen now except in the ancient remedy for nasal catarrh, and the use of the torch is merely whimsical or exotic, as in salmon-spearing or as in the revels of schoolboys.

§ 178.

One factor exercising a great influence on the later history of the candle was that as street lighting improved it became unnecessary to walk at night with a torch or "link". Before this happened, torches were at least advisable. You might carry your own tow link, or hire a link-boy, or, in Paris, hire the link itself at one of the street booths or kiosks erected under the monopoly of the Abbé Laudati. They went out of use very slowly. Thackeray speaks in *Vanity Fair* of "the laced lackeys and link-boys who used to put out their torches in the

blank iron extinguishers that still flank the lamps over the steps". These extinguishers we may see still. In Thackeray's day, however, the link-men carried not torches but lamps, and they plied for hire outside the houses of the rich, expressing to each issuing guest their profound hope that his honour had enjoyed the party.

§ 179.

As for the domestic fire, this seems to have started outside the door of the small primitive hut, which its owner had made by planting a ring of young trees and binding their tops together. When he progressed to the use of stone, he kept this hive-like shape. Later came the ridge-pole and an oblong structure; the fire was brought inside and a smoke-hole was made in the roof. For cooking, birds were wrapped in wet clay and baked, the skin and feathers coming away with the hard layers of brick. Meat and roots were buried in the hot embers or depended from a stick or laid on the burning logs. In treeless districts, there were animals portly enough to be grilled, as in later days men smelted glances and blendes in their own sulphurs. The first furnace or oven seems to have been a fire made in a pit, sometimes lined with stone—a far cry to such noble structures as the kitchen fireplaces in the London Mansion House, not yet demolished (1931) before which sixty fowls could be roasted at a time, to say nothing of great spear-like spits on which some cook's scullion would turn the barons of beef in the hot radiance of the flames. But developments of this magnitude required chimneys, and chimneys only came with the passage of time. In the day of Herodotus, the chimney was still, in general, no more than an

aperture in the roof, and the pool of sunlight on the floor is the key to one of his best stories.

In most early civilisations, since ventilation was poor, the effort was directed towards the suppression of unpleasant effluvia. Homer's Eurymedusa would replenish her fires with strips of oak, cedar or cypress which had been decorticised, water-seasoned and thoroughly dried. This is a recipe recorded by Theophrastus. In the Mediterranean civilisations, the use of unseasoned wood was the sign (if not of carelessness) of poverty, and Horace mentions an inn where his eyes greatly suffered on this account. Then the use of the fire-bason taught them how the most lachrymatory vapours might be toasted out of unseasoned wood before use, and the provision of half-charred chips, "ligna coctilia", became a distinct and separate tradesman's calling. It was followed for example, by the father of the emperor Pertinax. The next step seems to have been the lighting of the fire outside, the contents of the brasier or fire-bason being in a glowing state before they were brought into the room. It was doubtless the demand for material of a similar kind to feed such a fire that began the domestic use of charcoal. Such fire, too, was enclosed in iron vessels, provided with a blowpipe, resting in a hollow of the floor beneath a wooden cover over which a rug was spread. Radiators of this kind were in use in Persia at least as late as the beginning of the nineteenth century.

Perhaps owing to the fumes of carbon monoxide, a gas which was probably the "fire" that Portia "swallowed", the device now called Central Heating was introduced about the time of Seneca. It was a plausible

imitation of the circulation of heat in that other microcosm, the human body. This burned the fuel in a cellar and circulated hot air by pipes of lead (a metal used also for roofs and aqueducts) throughout the building. The tripod chafing-dish of the Greeks and Romans, placed in the centre of the room and fed with torches when light was required, was long preserved by the Turks, and is perhaps no very remote relation of those bedwarmers of the sixteenth to nineteenth centuries which immediately preceded the era of hot-water bottles and the electrically heated blanket. Charcoal is not made nowadays except for the artist and for the gunsmith. Gunpowder is still manufactured from the wood of the alder, the willow, the poplar, the aspen, the birch, the yew, the vine and the oleander. They cut the wood in the spring and dry it for some thirty or forty months before it is burned.

§ 180.

Towards the end of the seventeenth century, there was a sudden and enormous increase in the exploitation of the English coal-measures. Shipping had grown and tillage had spread, but the great reason why the forests had been stripped—the Weald, for example, being permanently lost—was to make charcoal for the glass works and iron furnaces. Coal was mined in the North before A.D. 850, and, in 1239, a Newcastle coalfield received a formal charter from Henry III. For a long time, its employment was of very small dimensions and its use domestically in chimneyless houses was a local criterion of the direst poverty. Elsewhere in Europe, its existence was little known. About 1300, there appeared the classic work of Marco Polo, the Venetian, and it is clear, from

his description of coal in Cathay, that he had never heard of it before. ". . . the black stones which they dig out of the mountains where it runs in veins. . . . It burns like charcoal, and retains the fire much better than wood; insomuch that it may be preserved during the night, and in the morning be found still burning. These stones may be had in the greatest abundance and at a cheap rate". There is one solitary reference to coal in Paracelsus, who died in 1541: he says that these black stones have been made out of ordinary stones under the action of Ætnean fire, an allusion to the acrid stinks of half-burnt sulphur compounds which pervade the gas driven off when coal is distilled. By 1600 it was in use in London, being brought from the Tyne by coasting vessels, and hence termed, as for example in Bacon and Shakespeare, "sea-coal". "Sea-coal men use some mixture of sea-coal with earth or chalk, privily, to make the bulk of the coal greater", says Bacon. In 1653, Izaak Walton, in his *Compleat Angler,* refers to "Tyne, famous for Newcastle, and her inexhaustible coal pits". About 1740, there came another boom in the use of coal for the smelting of iron.

§ 181.

Long before this, however, the domestic use of coal had grown to such an extent that the atmospheres of cities were vitiated. Even before 1661, when Evelyn published *Fumifugium,* the fogs of London were greatly increased and a formal remonstrance arrived from the banks of the Seine that the vines of France were being ruined by the smoke of London. Modern aerial surveys by aviation show that the smoke-hazes from cities may indeed drift to regions which are even hundreds of miles

distant. These domestic fires were lighted with wood shavings or tow with sticks; and, in the North, with dried sea-weed. Newspaper at this time was not regarded as refuse.

§ 182.

It is helpful to bear in mind the various fuels and flames with which people were familiar, in view of the fact that one of the small important sources of pneumatic chemistry was a false theory of colours, more especially the idea that blue, the colour of a cold person, was itself Cold. It is true that while Mankind has generally accepted the association of redness with heat there has in mystical systems been some amount of hesitation in the association of Blue with Evil. This is not true of backgrounds where blood was a taint or symbol of guilt that had to be mitigated by measures of purification. Paradoxically enough, it refers to systems where blood was the symbol of worship. To the Egyptian, Red was the life-blood of Isis, but some confusion arose when the red Set, the kindly Vulcan or Hephaistos of the earlier Pantheon, evolved by opposition with the divine Osiris into the principle of Evil. Moreover Blue was the colour of the adored Water-god, it was the colour of the celestial Fire, it was latent in the lapis lazuli. Thus Good and Evil, both at times confusedly identified with Red—Good especially in ideas of Resurrection—were most usually typified in White and Black. The sandals of Horus and the crown of Osiris, these were not Red but White. So in the Jewish system we find Blue associated with Purity, and Red with Sin as in "The Scarlet Woman", an epithet plagiarised by Wesley as a description of the baleful Roman Church.

Apart from these examples, Blue is almost universally Cold. White remained in derivative thought, however, not only as Luck but as Truth. Truth was especially the attribute of Osiris, and it was for Truth and Precision that the spirit-soul was weighed against the feather of Truth: it must be exact, neither too light nor too heavy. So Roman thought has given us for Truth the word Candour, the seeker of his townsmen's suffrages was arrayed in White, and man not only marked fortunate days with a White Stone but, from Homer onward, found a protection against Evil in the White Flower. Yet the historical sanction for the belief that Blue is Cold is almost as authoritative and just as picturesque as the ground on which red was associated with heat. Blue Snakes supported the blue bench of the Mexican god of terror. His forehead was blue. His club was blue. His staff was a blue snake curved in spiral. His girdle was of gold. In the Chinese mythology the dragon at the North Pole—which never saw either Sun or Moon—was a blue one. In Virgil, the snakes interwoven with the hair of the Hell-inhabiting Furies are blue snakes. Blue for low spirits has passed into slang. Men are blue when their central fires are so low that, as Dante puts it, they are "sad even in the sweet air irradiated by sunlight", because they "carry a foul and lazy mist within".

Flames burned blue in the presence of ghosts and devils because of their cold. This cold has been devoutly attested by tortured women charged with having suffered their embraces, and Shakespeare makes a cold to emanate from Cæsar's ghost that chills both the blood of Brutus and his taper; but, when Brutus *collected* himself,

the ghost vanished. When Faustus received an illustrious visitor, he "was suddenly taken with extream cold, as if he would have frozen in the place where he sat, in which the greatest devil in hell appeared unto him, with certain of his hideous and infernal company". So Chinese evil spirits froze mortals with their breath, unless the mortal got his blow in first; then, contrariwise, the evil spirit was incinerated. So also Pliny believed that human breath would incinerate that cold spirit, the serpent. So Tertullian—more exclusive—taught that the breath of any churchman would burn the Demon.

The importance of all this lies in the suggestion that the flames of charcoal, alcohol and sulphur possessed only a moderate heat as compared with the flames of wax and wood; and, above all, that the inner regions of the flames of wax and wood were cold. They resembled for example the will o' the wisp of the unhealthy marshes or the blue smoke which ascended from houses where lay those dead of the plague. Now just as plague-water was blue, for it held exhalations which had broken through the crust of the cold ground, so it was as a blue flame that the plague virgin traversed the Air and developed on the lips of the dead and the dying. Agricola points out that even the flame produced when a blast is driven through a charcoal fire is blue. Mayow, then, typical of his time, said that in the flame of burning sulphur, the nitro-aerial particles did not yield their customary red glow, which was due to their great heat, or mechanical agitation, "but, on account of their diminished motion, appear of an azure colour". To account for this, he adopts Hooke's idea of a diluent, "some third material, mixed with the nitro-aerial and sulphurous particles, by which the freer

movement of these igneous corpuscles is clogged". He mentions that anything combustible, except sulphur itself, can be held in the flame of sulphur for some time without taking fire; even a finger may be held in it, for a discreet period, he says, without any hurt. With this cold, blue flame he compares the expiring flame of the lamp, and he points out that the colours are similar.

§ 183.

Hooke is generally credited with the proof of the comparative coolness of the inner region of the flame. He certainly proved it independently. "In the middle of the flame of the candle", he writes, in Observation 20 of his *Micrographia,* "neer the top of the snuff, the fire or dissolving principle is nothing neer so strong as neer the bottom and out edges of the flame; which may be observed by the burning asunder of a thread, that will first break in those parts that the edges of the flame touch, and not in the middle". The priority in this proof must go, however, once more, to Bacon; and priority in the explanation goes to Shakespeare. Bacon says:

> "Take an arrow, and hold it in flame, for the space of ten pulses; and when it cometh forth, you shall find those parts of the arrow which were on the outsides of the flame more burned, blacked, and turned almost into a coal, whereas that in the midst of the flame will be as if the fire had scarce touched it. This is an instance of great consequence for the discovery of the nature of flame".

He adds that this demonstrates "that heat or fire is not violent or furious, but where it is checked or pent", and quotes with approval the contention of Aristotle's followers that "the pure elemental fire, in its own place, and not irritated, is but of a moderate heat".

Elsewhere, in the same *Natural History,* he writes :

> "There is an ancient received tradition of the salamander that it liveth in the fire. It must have two things, if it be true, to this operation: the one a very close skin, whereby flame, which in the midst is not so hot, cannot enter. . . . The other is some extreme cold and quenching virtue in the body of that creature, which choketh the fire".

(It will be remarked that Bacon has lost the old idea of a salamander as a fire-spirit, and is thinking of the lizard—a mistake found also in the autobiography of Benvenuto Cellini.) Clearly Bacon is not done justice in the preface to this *Sylva Sylvarum,* which concludes "it hath nothing of imagination". This work did not appear until after 1626. Twenty-four years earlier, Shakespeare's version of *Hamlet* was entered in the *Stationers' Register*; this was printed in quarto in 1603, and in folio in 1623. In this play, one of the characters states this scientific fact, which contains the explanation that Bacon sought and Hooke independently found :

> There lives within the very flame
> A kind of wick, or snuff, that will abate it.

§ 184.

Hooke gives us full details of the operation, so that there is the quality of an echo in the words of Accum, 100 years later, where he is trying to reconcile reluctant householders to the use—against nature as it was!—of lamps without wicks : "The whole difference consists in having the distillatory apparatus at the gas-light manufactory, instead of being in the wick". Hooke's explanation is given in Observations 6 and 20. The liquid or melted fuel rises in the wick for the same reason as water stands higher in an open tube than in a reservoir

surrounding it. Then it boils, and through a microscope there may be seen "an Ebullition, or bubbling, of the oil as high as the snuff looks black". These hot vapours compose the inner portion of the flame, and they rise, being lighter than the air. The higher the portion of the wick from which they issue, the less chance have they of being "preyed upon or burnt" by the "dissolving principle" in "the current of rarefy'd air and flame" sweeping upward. Accordingly, these steams are merely charred into "smoaky particles" which form accretions on the wick, or pass into the air; but these, "being by any means expos'd to the fresh Air, or that Air which encompasses the flame, they are presently lick'd up and devour'd by it, and vanish". Hooke watched wood burning too. "The reason", he says, in Observation 16,

> "why uncharred wood burns with a greater flame than that which is charred, is because waterish and volatile parts issuing out in vapours or wind become like so many little *aeolipiles*, or Bellows, whereby they blow and agitate the fired part, and conduce to the more speedy and violent consumption or dissolution of the body".

So the moisture, or mercury, or phlegma, came off first in strict concord with tradition, and was followed by the sulphur, or inflammable principle, or principle of cohesion.

§ 185.

Now the Peripatetics taught a distinction between the dusts and the dews of the atmosphere. Vapours were hot and moist; exhalations were hot and dry. It cannot have escaped them that "hot and dry" was an attribute common to "exhalations" and to "fire". In 1659, Shirley printed a "description of a well and earth in Lancashire

taking fire by a candle approached to it". This was near Wigan—

> "a place upon the borders of Lancashire", says Boyle, "where the water and mud of a ditch is so copiously impregnated with subterraneal exhalations (whether they be bituminous, sulphureous, or of some unknown kind), that they may easily be fired at the surface of the water, or earth, and made to burn like a candle, as an ingenious man did, at my request, successfully try".

Describing the same place, the Rev. John Clayton, Dean of Kildare, says "The water would seemingly burn like brandy". He writes to Boyle, five years later, to say that he "observed that there had formerly been some coalpits in the same close of ground". He therefore took home some coal from a neighbouring pit, and distilled it. We give his description of the operation in detail, for it was the first preparation of coal-gas.

§ 186.

> "I then got some coal from one of the pits nearest thereunto, which I distilled in a retort in an open fire. At first there came over only phlegm, afterwards a black oil, and then likewise a spirit arose, which I could noways condense, but it forced my lute, or broke my glasses. Once, when it had forced the lute, coming close thereto, in order to try to repair it, I observed that the spirit which issued out caught fire at the flame of the candle, and continued burning with violence as it issued out in a stream, which I blew out, and lighted again, alternately, for several times. I then had a mind to try if I could save any of this spirit, in order to which I took a turbinated receiver, and putting the candle to the pipe of the receiver whilst the spirit arose, I observed that it catcht flame, and continued burning at the end of the pipe, though you could not discern what fed the flame. I then blew it out,

> and lighted it again several times; after which I fixed a bladder, squeezed and void of air, to the pipe of the receiver. The oil and phlegm descended into the receiver, but the spirit, still ascending, blew up the bladder. I then filled a good many bladders therewith, and might have filled an inconceivable number more; for the spirit continued to rise for several hours, and filled the bladders almost as fast as a man could have blown them with his mouth; and yet the quantity of coals I distilled were inconsiderable. I kept this spirit in the bladders a considerable time, and endeavoured several ways to condense it, but in vain. And when I had a mind to divert strangers or friends, I have frequently taken one of these bladders, and pricking a hole therein with a pin, and compressing gently the bladder near the flame of a candle till it once took fire, it would then continue flaming till all the spirit was compressed out of the bladder; which was the more surprising, because no one could discern any difference in the appearance between these bladders and those which are filled with common air".

The year following, Becher came to England, bringing with him his method of making tar by distillation of fuel in retorts. He seems to claim the invention of making coke from pit-coal, and of charring the Dutch peat, but both these things were already practised. The immediate interest in his work is that he attempted smelting with the long flames from coal, "the flames extending so far", he says, "that a foot of coal makes flames ten feet long". He did not, however, try to "save" any of the flame.

§ 187.

Clayton, indeed, provides the first record in history of the isolation and collection of an artificial or factitious gas not produced, as Boyle's were produced, in the

receiver itself. It had always been regarded as peculiar to the essential nature of a discarnate spirit that it was free. Tales of its subjection and confinement were fabulous and things of wonder. So Zeus might confine Ares, an insubordinate god, in a brazen pot, or Jehovah Satan, or Solomon a djinni, Maui or Æolus the winds, Virgilius the devil, or a witch her familiar. (A witch in Reginald Scot kept her devil in *two* bottles!) In his famous *Antiquities,* Brand tells us that it was a supposed remedy against witchcraft to put some of the victim's water, corked in a bottle with some pins, needles and nails, in front of the fire, "in order to confine the spirit". "This sometimes did not prove sufficient, as it would often force the cork out with a loud noise, like that of a pistol, and cast the contents of the bottle to a considerable height". This was a counter-witchcraft by the sympathetic identification of similar objects, like the melting of the waxen image of the victim: if one spirit prevailed, so did the other, and so might both be constrained.

There is no record of any feeling that the enclosure of air itself was remarkable. (Even to Boyle and Hooke the remarkable thing about a bladder of air held in front of the fire, was that it burst.) A spirit or a wind (which was a quick thing generated at the Cloud Level by a conflict of vapours), that was a very different matter. But air had been enclosed from time immemorial. Rafts that brought goods down the great rivers were buoyed with blown sheep skins which were deflated and returned. The ancient bellows we have mentioned. Similar arrangements, known as bagpipes, have been used by many savage tribes to provide a rudimentary wind-music. In Homer, Æolus handed over the control of contrary winds

to Odysseus by shutting them in an ox-hide case. Wine-skins and waterskins are mentioned in *Joshua* and *Job* and in the *Book of the Dead,* the tied or plugged skin providing the Ancient Egyptians with a hieroglyph for drink. Now these skins, that they might be shaved, and that they might be preserved from cracking and creasing and breaking their bands asunder, were inflated. In this condition they provided obvious food for crude wit and so we have a devil in a skin waddling to do obeisance to Solomon or we have murderous slaughter done upon blown skins by an Apuleius or by a Don Quixote. The Ball Game appears in the mythology of the Mayas; and in Iranian folk-lore, such a game was played by Ormuzd and Ahriman. "Water-wings" were invented at least early enough for Julius Cæsar to use them.

By the time of the childhood of Augustus, blown bladders contained in casings were used in boys' organised games. (These had long included a "common ball" or Rugby.) Boys, however, continued and continue to blow up pigs' bladders for themselves. If the bladder misses the goal we may still hear that the Devil is in it. The Roman workers in vermilion (with which they plastered the statues of the gods) wore bladders as respirators. Bladders were a part of the scanty stock of Shakespeare's starved apothecary before he retired on the strength of Romeo's legacy.

§ 188.

It is generally supposed that the alchemists believed that the effluvia liberated during their operations could not be enclosed, and this is in accordance with all the background of thought which we have tried to paint in; but if this be true, who were the false reasoners to whom

Paracelsus alludes where he writes: "Air cannot in any way be enclosed, as some falsely think, for this reason, because at once, in the moment of separation, it levitates itself, and sometimes bursts forth as wind?" And what does Paracelsus mean, when later, in the same *Archidoxies,* he writes: "Having received the element of air in a perfect glass vessel, and hermetically sealed it, you must . . . etc", and, further, "Take a body, finely pounded, place it in a glazed pot, seal it with the seal of wisdom so that it shall not breathe forth. . . ." Indeed, over and over in the alchemical writings, we find injunctions as to the careful luting of the vessel in which distillation was carried out under reflux without any release of pressure. This was all very well so long as permanent gases were not formed, but in that case either the cement was ruptured or the philosophical egg was ruined. Paracelsus seems to have met the difficulty by employing a perforated iron capsule. In this way he was able to distil cinnabar in an earthenware pot.

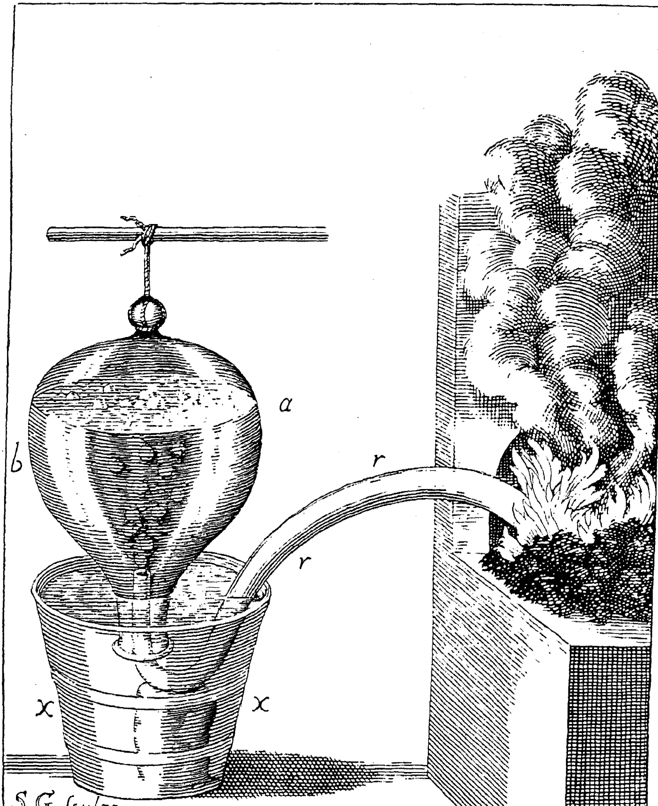
If the alchemists collected "airs", they kept the process a secret. Van Helmont certainly felt that he had made a new discovery when, mixing various substances which, as neighbours, produced an effervescence, he was able to break closed vessels without the application of heat. What had he done more than Pliny or than Paracelsus and Norton, who noticed the poisonous products of smouldering or the extinctive gas produced by flame, more than Bacon, who poured aqua fortis on metals, guarded against the "poisonous vapour of charcoal", and recommended the use of nitre, not only as a morning draught ("whereof he took the quantity of about three grains in thin warm broth every morning for

thirty years"), but heated on a fire-pan and inhaled for the cooling and condensing of the spirits—apparently the first use of oxygen gas in medicine? His achievement was that, like the ancients, who held their ears in the fume of vinegar to cure deafness, he began to distinguish properties among these exhalations, by which they might be identified, and he contributed to scientific vocabulary one of its hardest-used words. He derived "gas" from "chaos", which is in consonance with the ideas of alchemy; it seems to have been no fault of his but a consequence of the traditional belief in an indwelling spirit, that his contemporaries connected the word with "geist" or "ghost", and preferred the term "airs". Van Helmont at first called all his produced exhalations "gas sylvestres", but, when he found that some were not inflammable and some were, he called the latter "gas pinguë"—"fatty gas" or "fuel gas" or, in nearly contemporary English, "inflammable air".

§ 189.

Further work on the collection and isolation of gases clearly depended on the development of a method for releasing the pressure without losing the gas. Clayton's contrivance was good as a stage in the progress, but he found, as Bacon did, that a bladder was liable to take its own part in chemical operations. An enormous bladder, in shape grotesquely like a bird, was employed as an airship by Bartholomeu Lourenço de Cusmao, a Brazilian monk, who in 1709 rose, in his "Passarola", as high as the third storey of the King of Portugal's palace at Lisbon. At a second ascent, if the King were dreaming of the exploits of the Magic Horse of the Magus in the

THE SOUL OF NITRE.



HALES COLLECTS THE BAND OF UNION.

(This is the first known preparation of Oxygen.)

[Facsimile of the plate in *Statical Essays*.]

Arabian Nights whose "body became filled with Air" when its rider "turned the pin of ascent", his dreams were shattered. The contents of the balloon attracted some heavenly, or other, fire; and the now enlightened monarch forbade any further flying whatever on pain of death. Flying machines, he announced, were contrary to Divine Law. Hales arrived, at one leap, at the essentials of modern laboratory practice by suspending a flask upside down in a bucket. The flask had at its base (now at the top) a celestial ball, such as often crowned the Egyptian deities and is still often made on the bell-jar—a contrivance known to Solomon—and it was hung by string tied round this ball from a horizontal rod or beam above it. The flask was full of water, and there was enough water in the bucket to cover the mouth of the flask. The tube from the retort was bent round and up into the flask. It was in this apparatus that oxygen was first isolated. The superiority of the beehive shelf arrangement, later introduced by Priestley, is a very debatable point. The beehive shelf is not seen nowadays save in the laboratories of the secondary schools.

§ 190.

Between the death of Hooke and the birth of Priestley, Hales seems to have distilled everything he could lay his hands on, recording quantitatively how much "air" was obtainable. He prepared oxygen from nitre, and measured the amount, but that is all he records about it. So also he distilled hog's blood, sea-coal, fallow deer's horn, tallow, oyster-shell, heart of oak (fresh cut), dry shavings, green Indian wheat, mustard-seed, amber, tobacco, oil of aniseed, oil of olives, honey, beeswax,

sugar, brandy, water from several places, and finally the *calculus humanus,* for which he was trying to discover a solvent. Like the bezoar-stone it was an animal concretion, but it was human, and so even more important among the "Galenicals" (as opposed to the "Chemicals") in the Pharmacopœia of the time. Some of these substances, on distillation, yielded inflammable gases. Green pease furnished another example. Hales indexes the gas obtainable from green pease as "Distilled Flame". This is perhaps our most interesting and picturesque clue to the manner in which flame was now regarded. The dark aereal fuel was "flame"; the shining sheath which was its boundary with the confining air was "shining flame". The *flame,* said Hooke, was "nothing but the parts (of the oil) rarified and raised by heat into the form of a Vapour or Smoak".

> "They are not turned to *shining Flame* till they rise toward the top of the cone, where the free air can reach and so dissolve them. With the help of a piece of glass, anyone will plainly perceive that all the middle of the Cone of flame neither shines nor burns, but only the outward Superficies thereof that is contiguous to the free and unsatiated Air".

So, when sulphur boiled, Mayow refers to it as a boiling out of the *flame.* There is classical precedent: Aristophanes wrote of "adding flame to fire". So, as late as 1776, Congreve in *Love for Love* uses "fire" to mean fuel. In Basil Valentine, methane blowers are "fire coming out of the rock". The gardener's "fire" in soot is less probably the beneficial phlogiston of alkali than the carbon monoxide which, as Priestley found, soot occludes.

§ 191.

But this flame was only a vapour, or smoke, because it was hot: and the next advance was a retreat to that

view of flame which was held by Bacon and by Boyle and by the alchemists. It was the soul, not the spirit. Paracelsus and Bacon both thought it like air, only finer; Boyle thought it might "make coalitions". This view had been forgotten; hence Clayton's astonishment that his coal-gas "would in no ways condense", and Hales' fascination by the fact that the products of his distillation were "true air, and not a mere flatulent vapour". Hence, too, the surprise of those who came across the first methane "blower" to be described in England that this "fire" was quite *cold*. Two hundred years later, we can only faintly surmise the conflict of prejudice in the minds of these men: the exhalations came up out of the Earth; therefore they must be cold, evil and corrupt: but they *took* fire; therefore it was an astonishing thing that they were not hot.

It happened a year after the publication of Hales' book that in 1733 Sir James Lowther sank a pit to drain one of his Whitehaven collieries. At 42 fathoms, that black stone which covers coal was reached, and this, being pricked, let out "a vast quantity of damp, corrupted air", which took fire at a candle, becoming a flame half a yard across and "near two yards high". The flame was blue at the bottom and more white towards the top. When they enlarged the hole, "it burned a full yard in diameter, and about three yards high. . . ." They "enclosed" some of this air in bladders.

> "Tied close, it may be carried away and kept some days. Being afterwards pressed gently through a small pipe into the flame of a candle, it will take fire and burn at the end of the pipe as long as the bladder is gently pressed to feed the flame; and when taken from the candle, after it is so lighted, it will continue burning till there is no more

> air left in the bladder to supply the flame. The air, when it comes out at the top of the tube" (the vent which had been constructed) "is as cold as frosty air".

Reprinting this in 1809, the abridgers of the *Philosophical Transactions* of the Royal Society remark, in a footnote, "This gas was hydrogen", being unaware of Volta's demonstration in 1776 of the chemical difference between methane and hydrogen. The remark is particularly rich, since it decorates the same page as the statement:

> "It is to be observed that this sort of vapour, or damp air, will not take fire except by flame; sparks do not affect it, and for that reason it is frequent to use flint and steel in places affected with this sort of damp, which will give a glimmering light that is a great help to the workmen in difficult cases".

It will be readily understood that such blowers have long been the scenes of fire-worship. In the famous fire-temples at Baku, a hollow cane was inserted in the ground near the altar, the gas rising through the channel of the stick to burn at the top as a sacred flame.

§ 192.

In China, this natural gas had been for some time very usefully employed; not, indeed, as early as Marco Polo, though even then the baths, houses and factories were warmed with coal, stoves being let into the houses and fed from the outside, as if they were wide-necked aludels let into a furnace: but some time later, and at a date yet so early that in 1846 it was impossible to say when the custom had started. Borers for saltwater had been disturbed, in their frequent pricking of coal-beds, by jets of gas which rose to twenty or thirty feet. The gas was therefore led to the saltworks, through bamboo

pipes, and used as a fuel to evaporate the brine. Some of the surplus was taken to the houses for kitchen use and employed to light the streets, but since, even so, it could not all be used, the remainder was burned away at chimneys outside the saltworks. Such scenes are now commonplace in the United States of America.

Meanwhile Europe was solving its problems in its own way, and that was the employment of the gas which Clayton and Hales had derived from pit-coal by distillation. Like the Chinese natural gas, it might be conveyed along pipes, and it would not condense—not all of it.

§ 193.

The contemporary discovery that the atmosphere itself was a mixture of gases and the vapours of liquids took away much of the wonder which was at first associated with vapours that would not condense, though it was long before the relation of the two states of matter was understood. Priestley, for example, noted with ingenuous astonishment that air bubbled through ether doubled its volume, an observation registering little advance on Boyle's statement that the steams of boiling metals are dispersed in the atmosphere; and Newton was content to repeat the remark of Isidorus, of the seventh century, that flame was "burning smoke", *fumus candens.* "The gross fume which arises from them, before they flame, is the inflammable air they contain", writes Priestley. That recalls Boyle on hydrogen: "stinking fumes", "this stinking smoke", "a disposition in the smoke to inflammability". Twenty years after the discovery, by Cavendish and by Scheele, that inflammable air would burn at the end of a hollow glass cane, Sir Walter Scott

was writing to a friend: "There is a madman proposing to light London with—what do you think? Why, with smoke!"

§ 194.

By the end of the eighteenth century, the use of coal had become general, and Evelyn's *Fumifugium* was doubtless completely forgotten. In 1785, J. P. Minckelers illuminated his lecture-theatre at Louvain with coal-gas. In 1787, Lord Dundonald used the coal-gas from his tar-works to light up the hall of Culross Abbey. About the same time, William Murdoch distilled coal, and lighted his house at Redruth with the gas, storing it under pressure. In 1798, Murdoch was attracted to the service of a Birmingham firm manufacturing steam-engines, directed by the inventor, Watt, who was intensely interested in Priestley's work and in Murdoch's own work, both on engines and on gas. Their factory was illuminated with coal-gas before the year was out. Four years later, they gave a public display. In 1805, the cotton-mill of Messrs. Phillips & Lee in Manchester was similarly lighted, and, in spite of the opposition of Watts and Murdoch, the zeal of F. A. Winsor, a Moravian company promoter, was such that coal-gas entered the market as a purchasable commodity, this artificial illumination of factories being regarded as fresh proof of the march of progress. It was actually a fresh link in the vicious circle of daylight fog and murk which made artificial lighting necessary.

§ 195.

The public was not friendly. Lamps without wicks! Fire travelling along pipes without heating them! Like

all breaks with old tradition, it was contrary to Divine Law. We have mentioned already how Accum tackled this difficulty: they had only moved the still-head; the material of the little jets of smoke issuing from coal in the fire was such that it might be "conveyed by means of pipes and branching tubes to any required distance, in order to exhibit it there at the orifice of the conducting tube, so that it may be used as a candle or lamp". Coal-gas was for some years the butt of comic broadsheets, and furnished gentle fun to Thackeray, to Dickens and to Keats. Keats employs it in his little doggerel fantasy *Cap and Bells*:

> It was the time when wholesale houses close
> Their shutters with a moody sense of wealth,
> But retail traders, diligent, let loose
> The gas, (objected to, on score of health),
> Conveyed in little soldered pipes by stealth,
> And make it flare in many a brilliant form,
> That all the powers of darkness it repell'th,
> Which to the oil-trade doth great scaith and harm
> And supersedeth quite the use of the glow-worm.

Practice toiled valiantly after knowledge. Invention of a high order was necessary, and it was provided. The infant industry was to be largely indebted to William Henry for an accurate investigation of the chemistry of coal-gas, and of the different stages of its production; and no whit less to Clegg for the mechanical devices (covering preparation, purification and measurement) without which the enormous extension of its use would have been impossible. Most of those who are adult at the present day must have been in houses where, succeeding upon a sudden religious dimness, there came a chorus "They're lighting up next door". In the early

days of the industry, when meters and governors were in the experimental stage, the gas had to be supplied on the bare undertaking, supported by no penalties, or possibility, indeed, of conviction—since the Englishman's house at that time was truly his castle—that it would be used only during specified hours by a specified number of specified burners at a specified height of flame. In any event, the moment the theatres and large halls closed down for the night, gas roared wastefully through the flares of the neighbouring establishments. One prejudice against the use of coal-gas was furnished by explosions. Accum explains that this is due to faulty workmanship and an escape of gas which must be looked for with the help of a lighted taper! Another prejudice, as we have seen, was that the gas, since it must naturally heat the conducting tubes, would thus set fire to the houses!

§ 196.

In spite of all, though the streets of London were not lighted with gas till 1812, seven years later more than 51,000 gas-lamps burned there nightly. Within the same few years, installations had been made in the other principal cities of the kingdom. Great strides had been made in the separation of carbon disulphide and "sulphuretted hydrogen" from the "carburetted hydrogen", and the problem of even pressure was well in hand. Other sources of gas were also being examined. Le Bon had achieved no satisfactory result by using wood—though it was his work, demonstrated at his own house, which in 1799 had aroused the interest and emulation of Winsor—but Pettenkofer remedied the poorly illuminating character of the wood-gas by "cracking" the heavy oils

(Hales' "inelastic air in oils") which were a bye-product of the process. In 1805, a step was taken which not only disarmed the hostility of the oil-trade, but enlisted it as a prized ally; this was the discovery of oil-gas by Henry. Under his direction, J. and F. Taylor set up a large-scale distillery, crude whale-oil being made to drip, drop by drop, into red-hot retorts. The gratified oil-merchants found that for this purpose it was quite unnecessary, and in no way beneficial, even to purify their oil. This oil-gas gave a brighter light than the oil from coal, and was used to enrich it. Under the name of "portable gas", that is, compressed in cylinders, it was later to be used on the railways.

§ 197.

There were some analogies with the lamp and candle which were somewhat disconcerting. The device of Simonides' Fourth Knight in *Pericles* was

> A burning torch that's turned upside down;
> The word: Quod me alit, me extinguit.

Thus fire (as fuel) might smother fire (the activity), a paradox similar to the idea that fire was consumed by what nourished it. If one stopped short of this extreme, allowing the snuff to reach an inordinate length by tilting the candle over, the flame became extremely smoky, as explained on a previous page in a quotation from Hooke: combustible matter was leaving the flame in an incompletely burned condition. Just the same thing might happen with the new lighting device. Too high a pressure would, short of the extreme case where it blew the flame out, cause a similar wastage. "When the flame", says Accum, "is suffered to rise beyond the standard height,

the combustion of the gas becomes imperfect. Part of the gas passes through the flame unburnt and occasions the source of the offensive odours which the gaslights never produce when the combustion of the gas is complete".

In Accum's time, there were three burners commonly employed, the Batswing, which "exhibits a tulip-shaped flame", the Cockspur, which was wasteful, the combustion being imperfect, and the Argand. The Cockspur was merely a survival of Murdoch's temporary shift to moderate the violence of emission by soldering up his delivery-tube and then boring three holes in it. The Argand was an interesting essay in the proper aeration of the flame. In the tar-oil lamps on Waterloo Bridge, the air entered at the base of the lamp and passed out through the centre of what was optimistically termed the "reflector", above the flame. The Argand reversed the arrangement, the air entering inside the gas, being conveyed through a central brass tube concentric with the larger tube, conveying the gas, which surrounded it. It was similar, therefore, to the first Miner's Lamp of George Stephenson, which took in its air through a tube situated in the centre of the wick. The same principle led to the blast flame, when, in 1840, Delbruck conceived the idea of leading gas and air separately under pressure through concentric tubes to the burner.

In the gaslight, however, the trouble was not that smoke escaped unburned in minute solid particles, but that foul gases were formed in the flame and vented into the atmosphere. Actually the flame of coal-gas was not smoky enough : provided that the flame can be adequately aerated, it cannot be too smoky. Hence the ancient

appreciation of the "pitchy pine", and of "smoky Falernian" the only wine that would burn well. In the present instance, this was one of Davy's discoveries, and this was the reason why oil-gas was added to the coal-gas : it made the flame more smoky. He asserted that the natural light of coal-gas was due to incandescence, that is, to the incandescence of the carbonaceous particles chemically produced during the combustion. "The light of common flames", he says, "depends almost entirely upon the deposition, ignition and combustion of solid charcoal", and the luminance "of a common flame is proportional to the quantity of solid charcoal first deposited and afterwards burnt". Tyndall later amplified this by saying that "every solid particle rises with immense rapidity through the flame, describing a white-hot line, and the sum of these lines gives us the light of the flame".

There were other devices, besides the addition of oil-gas, for improving the luminance of the gas from coal, but they all hinged on Davy's discovery. In Frankland's Argand burner, the air was pre-heated, the particles being thus formed earlier and shining for a longer time. Frankland also investigated Davy's statement that luminance increased under high pressure, and made even methylated spirits burn with a brilliant white flame. J. B. Neilson discovered that the light was greatly increased when two flames impinged on each other.

§ 198.

The two most startling discoveries about the flame were derived from mixing with the gas one of the two principal constituents of the atmosphere. If nitrogen were added, the flame lost its luminance, being too cool

to set up the chemical actions in which the smoky particles are formed. If oxygen were added, the particles were not formed because their congeners were too quickly burnt. Also, in the latter case, the flame showed a disposition to dive into the supply-tube.

This was Bunsen's discovery. The admixture of oxygen in a gas supply is certainly a matter of academic interest only, but when air was used instead of oxygen the discovery at once assumed the potentialities of enormous industrial developments. We know definitely that Bunsen made these mixtures and burned them at the ends of supply-tubes, balancing the rate of supply against the disposition of the flame to burn back. It has also been stated that Bunsen noticed the effect of punctures in an upright supply-tube, open at the top: just as the pressure of water from a reservoir is higher in low places, so that of gas was lower in low places; just as water ascending a tube will squirt from orifices at the side, but in descent will suck in air from without, so, when coal-gas ascended a punctured tube, a region of low pressure was created near the orifice, air being sucked in to mix with the gas. Like Hooke, Bunsen was as great a master of manipulation as of reasoning, fusing his own glass joints, for example, with a laborious blow-pipe, and the invention of the famous burner was now inevitable. In 1856, Pettit and Smith applied this burner to the problem of the gas-fire, in which a row of Bunsen burners were made to heat contorted columns of refractory materials. This was a domestic blessing the value of which it is difficult to over-estimate; difficult, indeed, to estimate at its true value in these still better days of electric radiators.

§ 199.

The flame of the Bunsen burner was no good, however, as an illuminant. It contained no candent particles. But the lack of these small radiant bodies was more than made good by the invention of the incandescent mantle. This invention, again, did not spring forth fully developed from the brain of some new Jupiter. In 1826, Goldsworthy Gurney discovered the property of candency in a heated cylinder of lime. (A hundred years later, we still speak metaphorically of the limelight.) The extraordinary public appetite for lectures encouraged the development of the optical projection of pictures. In 1835, W. H. Fox Talbot showed that finely divided lime yielded a light equal to that of the "magic lantern" with a temperature no higher than that of the spirit-lamp. In 1848, J. P. Gillard made a fine mantle of platinum gauze. This gave a brilliant light, but was of short 'life' owing to the swift erosion of the metal. Bunsen's burner, produced in 1855, was a fresh stimulus to invention, however, and in 1882 at the Crystal Palace Exhibition there was shown the Clamond "basket", or mantle, a cone of threads of calcined magnesia, made by pressing a paste of hydrate and acetate through holes in a plate.

Auer von Welsbach — like Carius, Smithells and other famous chemists, a pupil of Bunsen—was at this time carrying out researches with the spectroscope on the "rare earths", heating his material on a platinum wire. He found that even a thread of cotton, immersed in the solution and introduced into the flame, continued to yield a light of remarkable brilliance. It was an easy stage from this to the idea of a mantle of cotton fabric immersed in a solution of the rare earths and then

calcined. In 1886, he protected the use of thoria by a patent, but found later that a trace of ceria was of the utmost importance. By 1893, the mantle was adaptable to the Kitson oil-lamp, now eight years old, wherein a "non-luminous" flame—as they term that of the Bunsen burner—was produced by using the waste heat of the burning oil to volatilise further supplies, the vapour being then mixed with air by a contrivance similar to Bunsen's.

§ 200.

We shall conclude this chapter with a comparison of the "common" flame—an epithet which is becoming a misnomer—with that of the Bunsen burner. In the "luminous" flame, whether wick-fed or burning at the end of a supply-tube, Berzelius found four regions, (*a*) the dark, central region, (*b*) the yellow, "luminous" region, (*c*) the blue region at the base, (*d*) the faintly luminous region lying between (*a*) and (*b*). To these may be added the faint super-aerated sheath surrounding the whole, which it is reasonable to regard alternatively as an extension of (*c*).

The aerated flame is immediately differentiated by the faintness of its illumination, "the feeble light of burning", as Davy called it. If air is in excess, it has one region only, and is called a "blowpipe flame". The mixture of gas and air must then be supplied from a narrow tube and at a high rate, or the flame will pass back down the tube. If the gas is in excess, the products of the combustion in the first zone are still inflammable and burn in the atmosphere making a second. Thus we have the typical inner and outer cones of the Bunsen flame. It is not sought at the present time to supply gas

as an independent illuminant. It is assumed that all users are sufficiently intelligent to supply themselves with the incandescent mantle. Hence gas is supplied which has a heating value only, and it is charged, quite equitably when the meters are in good order, on a heat basis. The chemical constitution of the modern gas supply bears little relation therefore to that of the nineteenth century, though parts of it still come directly from coal. A large portion of the modern commodity consists of water-gas or producer-gas, prepared by driving a mixture of steam and air through red-hot charcoal or coke. This mixture of carbon monoxide, hydrogen and nitrogen first came into use about 1880 as a cheap fuel for gas-engines.

§ 201.

The principle of illumination by a "white-hot" solid was further to be employed under the régime of Electricity, which in our own country followed hard on the heels of Gas. It was at first used with great vulgarity and display in public places, but our cities have recently been the scene of some extremely elegant experiments in what may be called the footlight system, the actual source of light being itself hidden. If we incline to plume ourselves on our use of this excellent principle of incandescence, let us turn once more to Adlington's Apuleius:

> "One of the principall Priests carried in his hand a light, not unlike to those which we used in our houses, saving that in the middle thereof appeared a bole, which rendred a more bright flame".

Much have we travelled in the realms of gold: it would be ungrateful to forget *The Golden Asse.*

CHAPTER X.

THE QUIVERING MANE.

Hast thou clothed his neck with the quivering mane?
—*The Book of Job.*

Sleek with youth through the casting of his slough he rears and rolls on.
—*The Aeneid.*

§ 202.

The comparative inflammability of fuels may be shown to depend on considerations so numerous that most investigators have abandoned the attempt to discover a basis of comparison. For example, there can be no standard test that would successfully compare the inflammability of a gas with the inflammability of a solid. Among solids themselves, we are immediately confronted by specific heat, specific porosity, specific temperature of vaporisation, specific heat of combustion. These conclusions are due primarily to Davy. He attempted to compose a list of inflammable substances in the order of their readiness to ignite. He had

Phosphorus
Sulphur
Hydrogen
Hydrogen sulphide
Ethylene ("Olefiant" or "Olifiant" gas)
Carbon monoxide
Methane

and this is how he arrived at his results. First he varied the temperature of the agent of ignition. He found that a piece of iron, or a piece of charcoal, hot enough to be

just visible in the dark, would ignite of the five gases on this list only hydrogen and hydrogen sulphide. Charcoal made red-hot would ignite ethylene and carbon monoxide, but would not ignite methane. Iron made red-hot, and even white-hot, failed to ignite methane unless indeed, at white-heat, the iron was itself aflame

§ 203.

Then he tried what may be called an extinction method, finding rather the order in which flames might be put out than the order in which they might be induced to appear. The fuel was ignited and placed within a vessel. Usually a platinum wire was suspended in the flame, experiments where this was done being indicated in our copy of the list by an asterisk. Then the vessel was gradually evacuated by a suction-pump until the flame expired.

Combustible.	Still in Flame at
Phosphorus Hydrides -	The best vacuum obtainable
Phosphorus - - -	1/60 atmosphere (a result due to van Marum)
Sulphur - - - -	1/15 to 1/20 atmosphere
*Hydrogen - - - -	1/13 atmosphere
*Ethylene - - - -	1/10 to 1/11 atmosphere
*Alcohol and a Wax Taper	1/7 to 1/8 atmosphere
*Hydrogen Sulphide - -	1/7 atmosphere
*Carbon monoxide - -	1/6 atmosphere
Alcohol - - - -	1/5 to 1/6 atmosphere
Wax Taper - - - -	1/5 to 1/6 atmosphere
*Methane - - - -	1/4 atmosphere

Without neglecting to notice the effect of the platinum wire on the flames of Alcohol and the Wax Taper, let

us rather emphasise at the moment that this method, wire or no wire, changes the order of the list; and Davy points out the importance, under these conditions, of the heat emitted by the combustion in predisposing the fuel to inflame.

It is already clear, therefore, that we cannot speak of the ignitibility, even of a pure chemical substance, as we should speak of a physical constant, rigorously independent of the circumstances of ignition. Perhaps the best illustration of this is to be found in Davy's record that at 1/18 of an atmosphere, mixtures of hydrogen and oxygen could not be ignited by the electric spark, except when he heated one end of the containing tube. On the other hand, we may certainly apply the terms highly inflammable and poorly inflammable as a summary of our impression of the general behaviour of a fuel.

§ 204.

Another of Davy's assessments of inflammability depended on the extinction of flames by inert gases, the molecules of which may be regarded as impeding the action of the molecules of oxygen. Thus this was another method of diminishing the rate of supply of oxygen to the fuel.

> "There is a very simple experiment", he says, "which demonstrates in an elegant manner this general principle. Into a long bottle with a narrow neck introduce a lighted taper, and let it burn until it is extinguished; carefully stop the bottle, and introduce another lighted taper; it will be extinguished before it reaches the bottom of the neck: then introduce a small tube containing zinc and diluted sulphuric acid, at the aperture of which the hydrogene is inflamed; the hydrogene will be found to burn in whatever

part of the bottle the tube is placed: after the hydrogene is extinguished, introduce lighted sulphur; this will burn for some time, and after its extinction, phosphorus will be as luminous as in the air, and if heated in the bottle, will produce a pale, yellow flame of considerable intensity".

§ 205.

He tried some further extinction methods which, like these others, were also a rough measure of the heat emitted by the combustion, for he found, in one series of experiments, that the smallest flame able to persist after the removal of the igniting agent was smaller with sulphur than with hydrogen, smaller with hydrogen than with a wick-fed oil flame, and smaller with the wick-fed oil flame than with methane. A ring of cool wire, too, that instantly extinguished the methane flame, only slightly diminished the size of a flame of sulphur of the same dimensions; thence he argued that the gauze of a safety-lamp in atmospheres containing hydrogen would have to be much finer in mesh than some which it would be perfectly safe to employ in atmospheres containing methane. If Davy's lamps were used, as he advised, in spirit-cellars, the margin of safety for the same lamp would be greater still in explosive methane mixtures.

§ 206.

His invention of the gauze safety-lamp owed much to these experiments, for though it was due logically to later work in which he studied the passage of flame along tubes containing explosive mixtures, eventually the wire was the thing. Now we have already seen how a hot wire will prolong the life of a flame under adverse conditions: the wire gauze of a safety-lamp may do more;

it may get so hot as to be itself an agent of ignition. Finally, therefore, we must mention a direct ignition method which showed Davy that

> "the combustibilities of the different gaseous matters are likewise to a certain extent as the masses of heated matter required to inflame them. Thus an iron wire of one fortieth of an inch, heated cherry red, will not inflame olefiant gas, but it will inflame hydrogene gas; and a wire of one eighth, heated to the same degree, will inflame olefiant gas; but a wire of one five-hundredth must be heated to whiteness to inflame hydrogene, though at a low red heat it will inflame bi-phosphuretted hydrogene gas; but wire of one fortieth heated even to whiteness will not inflame mixtures of firedamp".

§ 207.

Another interesting example of the ignition of inflammable gases at a hot surface is provided in the researches of Frankland on coal-gas. He found that either hydrogen or carbon monoxide, if mixed with small amounts of carbon disulphide, would take fire at the surface of a glass test-tube containing oil at 210°C.; yet crude coal-gas would not do so, because, though it contained carbon disulphide before its purification, it also contained ethylene, and a minute trace of ethylene will destroy in any gas-mixture that great ease of ignitibility which the highly inflammable carbon disulphide confers upon it. Dixon has shown that in such mixtures the carbon disulphide oxidises first to sulphur dioxide and a suspension of solid particles of carbon monosulphide, the chemical processes of combustion becoming more active at the surface of the particulate aggregates. Ethylene, acetylene or nitrogen peroxide in the mixture change the history of the oxidation, probably "by condensing on the

surface of the CS at an early stage, and so preventing its action as a nucleus". It is possible to base on this theory an explanation of the "cool flame" exhibited by carbon disulphide in common with ether, aldehyde, and the higher paraffins, if when they are for example in contact with almost spent air the temperature slowly rises. Such flames will pass through fine metal gauze, though the normal flames, into which when confined they rapidly develop, refuse to do so. It must not be thought that ethylene and acetylene are not highly inflammable. They are much more inflammable than methane. Nitrogen peroxide, too, normally creates by its presence an easier ignitibility, yet another discovery due to Dixon. At the time of his death, Dixon was showing how suspensions containing iodine provided a method of decreasing the ignitibility of gas-mixtures.

§ 208.

We have seen how Davy tried to determine the relative ignitibilities of combustibles from the size of the smallest flame which, in still air, would persist upon them. The minimum size of any such flame in oxygen is smaller still. Humboldt and Gay Lussac found that if a hydrogen jet, burning in oxygen, were reduced to its smallest size, the flame was minute, mobile, and slightly coloured; when air was substituted for oxygen, the minimum flame was larger, less mobile and more coloured. In proportion as the oxygen diminished, the hydrogen had to spread out, they said, to greater and greater distances in order to locate the oxygen. The flame became bluish-green and very soon afterwards expired. The flame becomes larger still, and still more brightly coloured, if

supported instead by an atmosphere of nitrous oxide, the outer cone of the triple flame being a powdery green.

§ 209.

In any attempt to estimate the comparative ignitibilities of combustibles, one must consider the temperature at which the chemical reaction will start. The application of the agent of ignition will be temporary, however, and a body is not conceived as combustible unless it will carry on its own combustion once this has satisfactorily started. Now the continuance of the chemical reaction must depend on the rate at which it proceeds and the heat energy which it releases. The comparative ignitibilities of substances must also, therefore, depend on these two quantities. But these may not bear any relation to the time taken for ignition which also is a criterion of ignitibility. These quantities, moreover, are not simple, nor are they easily assessed; they vary, too, with the circumstances of the ignition. A slow, flameless reaction may be started by the igniting agent, and this reaction may give off far more heat than it requires to maintain itself at its initial rate. The temperature rises therefore, increasing the rate of reaction, until a cool flame or even a normal flame, supervenes. But the rise in temperature may also change the identity of the reaction : when wood burns for example, the flame does not consist of air mixed with the vapour of the chemical constituents of wood; they are broken down by heat into simpler bodies. This is not to say that one fuel is not more inflammable than another; it does indicate, however, that two bodies may be so nearly alike in inflammability that their comparative order may be reversed by a change in the circumstances of ignition.

§ 210.

When spontaneous ignition occurs in turf, haystacks, manure-heaps or oil-saturated cotton-waste, the initiation is microbic. The gradually rising temperature puts a stop to this activity, but the medium is now liable to increased oxidation with further rises of temperature. At one time it was believed that spontaneous ignition in coalmines was due solely to the heat generated by the oxidation of iron pyrites present in the coal; and there seems little doubt that the presence of pyrites may sometimes be a contributory or even a determinant factor. Recent work emphasises the importance of the mode of existence of the pyrites. The main cause, however, is most often the direct action of the oxygen of the air on the coal substance. Coal is a conglomerate of widely different compounds, plant remains which retain their morphological structures and the products of decay of plants devoid of morphological structure. The latter, the "ulmin compounds", are the portion of coal most readily attacked by oxygen; from a chemical point of view the degree of liability of a coal to spontaneous combustion can be estimated by determining the proportion and character of the ulmin compounds which it contains.

These are all examples of the partial confinement of gas in enclosures which rise in temperature. Now when a gas-mixture is confined in a heated vessel and begins to suffer flameless combustion, it will begin to lose heat to the wall; for since it was originally at the temperature of the wall and is now developing heat, the wall will be at a lower temperature. Since the ratio of surface-area to volume changes rapidly with the size of the vessel, this cooling factor will become important when the vessel

is small, and it may prevent actual ignition. But the wall is heated, and thus a cycle of operations may be repeated as "smouldering". Let us consider a skeleton cellular tissue, such that any section is a gauze, but a gauze made of partially combustible fibre, not of incombustible wire. Combustion travels through the tissue as a slowly moving zone, bright red in the middle, but of a duller colour in front, where combustion is beginning, and dull also behind, where we have little beside the cooling ash. This may be readily observed by allowing a piece of brown paper to smoulder in the field of a microscope. As the zone approaches any given plane of the tissue, vaporisation, mixing, and pre-flame oxidation will begin. These intensify with the increase in temperature due to the approaching hot zone, and the vaporisation and oxidation reach their maximum as the plane becomes the centre of the zone. Other planes in the unburned portion of the tissue are now entering upon the same experience. Actual flame is not produced for the same reason that the smouldering will not spread below a certain depth of the tissue: there is not enough air. Moreover heat is lost in the free expansion of the burning gases and the solid matter acts as a cooling agent in the same way as Davy's gauze. Some smouldering bodies may be blown into flame, however, since this removes partially burned gas-mixture, intensifies the reaction, increases the vaporisation, and makes locally an explosive mixture which is fully aerated, and will yield flame, though only at the surface.

This, then, is the theory of tinder. Before ignition takes place we have—

i. a "pure-chemical" reaction: flameless combustion, involving partial oxidation, and the production of "end-products", for example, carbon monoxide, carbon dioxide and water.

ii. "thermo-chemical" reactions: (*a*) a breaking-down of the fuel, and often to some extent (*b*) a formation of substances of more complex molecular structure.

The mixture ultimately ignited is, in fact, not the mixture originally present. Thus it is very difficult to ignite electrolytic gas itself by heating it gradually in a vessel, because the flameless combustion tends to become complete. Similarly, a mixture of carbon disulphide and air will at very low temperatures (for example 90°C.) pursue a flameless combustion; and eventually the products of this render the remainder non-ignitible. Thus some fuels under some circumstances are so readily oxidisable that they do not ignite! It becomes evident that in attacking the problem of the ignitibility of fuels without some very rigid delimitation of the field, an investigator is chasing Puck. Let us, then, start afresh and equip ourselves with a little more preparatory knowledge. Perhaps Puck will turn up!

§ 211.

It is sometimes said of a fuel when it is easily kindled, that it "bursts into flame". This expresses very well the puff that is caused when a zone of gas near the surface of the material suddenly becomes so strongly reactive as to give out light and heat. The gas in this zone is a mixture formed by air from the outside and by the vapours distilling from the fuel on the inside

Each is a necessary constituent. That is why the wood-dust in the friction method must be blown upon. Otherwise the interstices become full of an airless fume. Once the flame is set up, it radiates sufficient heat to circulate the air and to keep the distillation going. In the normal burning of a morsel of fuel, the issuing vapours form a covering, so that the radiant shell of kindled gas-mixture does not touch the surface. We know that this is true of the candle-flame and the wick, but it is also true of all non-gaseous fuels. The distance of the radiant shell from the surface of the fuel depends on the violence with which the gases or vapours are expelled. Another example is offered by the common fire, where flames may shoot through the smoke (in the familiar reindeer's horn) downwards as well as upwards, and these downward moving flames may expire before they reach the coal that is contributing the combustible portion of the reacting gas. "Flame", says Dante, "feeding on combustible matter, glides along the surface, scarcely touching where it moves". We may not regard it as in any sense touching the surface except before and after the exhalation of the vapour or gas.

A much more pronounced puff may be obtained in the fireplace when there is some delay between the distillation and the ignition, because then the supply of gas ready for mixing and enkindling has increased to a much larger volume. This may be ensured and intensified by a slight alteration in the conditions. Part of the Autumn rubbish-heap in the open field may be sprinkled with petrol. Petrol needs only the warmth of the atmosphere to give off vapour plentifully. This vapour mixes with the air and hangs heavily in the interstices of the pile.

When the flame reaches it, there is a considerable disturbance and, momentarily, an enormous volume of luminous gas. The two effects are symptoms of the same thing: the zone of gas which is ignited expands very quickly, igniting neighbouring gas as it moves, to about six times its former volume, and the atmosphere near it is abruptly moved out of its way. Paraffin, a liquid similar to petrol, but a little less volatile, has often been used as an aid to firelighting. The force of the consequent expansion when some of the liquid penetrated the flues, mixed with the air there, and then took fire, has been responsible for many early morning disorders. If we may paraphrase Bacon on gunpowder, the force of the flame expelleth the soot into the room because there it findeth easiest deliverance.

Difficult therefore and unfamiliar as the thought may be, every flame is a flame in an explosive mixture. This truth was first stated categorically by Sir Humphry Davy. It was a result of the researches we have described, and probably owes nothing to a very similar statement made by Hooke (§161, 12). He says: "Whenever combustible gaseous matter burns in the atmosphere, it must first mix with a certain quantity of air", and again, "The flame of combustible bodies in all cases must be considered as the combustion of an *explosive mixture* of inflammable gas (or vapour) and air; for it cannot be regarded as a mere combustion at the surface of contact of the inflammable matter". When, for example, magnesium burns, the thought becomes still more difficult, until it is remembered that before the metal takes fire it is already at a temperature at which it has started to vaporise freely. Davy produced an actual proof of the

nature of flames from metals by preparing an explosive mixture of zinc vapour and air; to do this, it was necessary to raise the metal to red heat and to reduce the air-pressure in the chamber, but he overcame all experimental difficulties and obtained a mixture which duly flashed.

§ 212.

It will be clear that explosive mixtures of gases are inevitably accumulated under any conditions of imperfect ventilation where there is an issue of inflammable gas or vapour. Thus we have read of explosions in streets due to the decay of the bitumen which used to serve as the casing of cables, of explosions in culverts due to the percolation of coal-gas from faulty mains, of explosions in sewers due to the fermentation of refuse, of explosions in coal-mines due to the exhalation of firedamp, or methane, and of explosions in spirit-cellars or in the spirit-holds of ships. The memorable *Mary Celeste* carried 1,700 barrels of rum, and it has been powerfully argued that this explained her desertion by the crew: J. G. Lockhart writes: "Dr. Cobb believes that the clue to the mystery is to be found in the cargo". The suggestion is that the hatches were being opened to ventilate the hold when minor explosions occurred, sufficient in number to send everybody scuttling from the vessel; and that the ventilation now provided actually proved a sufficient preventive of any further combustion. When science, in the person of Davy, received the appeal of the mining industry that these explosions, particularly those in coal-mines, should be ended, Davy's conclusions, adopted by all subsequent investigators, showed that the first step in the new study involved

experimentation with simple homogeneous mixtures of pure gases.

§ 213.

One of the first results was the indication that explosions took time. Earlier scientists, intent on other matters, simply had not realised that the radiant shell travelling harmlessly from one end to another in an open vessel only differed from the flame of an explosion in having been offered an "easy deliverance". What they had realised was that an explosion happened very quickly indeed. Consider the result of the following experiment planned by Bacon: "Make a hole in the top" (of the oil-reservoir of a lamp) "and try, when the oil is almost consumed, whether the air made of the oil will inflame if you put to it the flame of a candle. It were good to have a lamp made, not of tin, but of glass, that you may see how the vapour or air gathereth by degrees in the top". If Bacon's laborant survived this experiment, he would be in a position of priority to O. Henry, who writes in *The Man Higher up*: " 'Oil', says I, 'never explodes. It's the gas that forms that explodes'."

A century and a half later, in 1776, there was an experiment by van Marum which would also seem to us extraordinary had we not explored in previous chapters the background of contemporary thought. Troubled by moisture in the working of his newly invented frictional electric generator—similar, apparently, to that of Hauksbee—and regarding the atmosphere not only as a menstruum of earthy and of fiery particles but also, in Mrs. Fulhame's phrase, "an inexhaustible magazine of water", he hoped that one of the novel "factitious airs", these artificially prepared gases, would be drier. He

therefore covered his machine with a great bell-jar, which he then flooded with hydrogen. When he re-started his machine, however, the contents of the bell-jar included air as well as hydrogen, and a moment later large fragments of thick glass were embedded in the furniture. Essentially, he had fired the same explosive gas-mixture as formed the charge in Volta's contemporary pistol. The labours of Lavoisier and of Priestley were also not without exciting incident, Lavoisier's broken vessels exhibiting a tiresome unanimity, since each, like that of the alchemist, described by Paracelsus as using a vessel of unorthodox shape, disintegrated into a thousand pieces. Lavoisier was probably the first investigator to demonstrate the power of alcohol as a contributor to gaseous explosions. He was able so to manipulate a red-hot iron wire as to touch a morsel of yellow phosphorus fuming in air which had stood over alcohol for some time under diminished pressure, thus increasing its content of alcohol vapour. The jar was thrown, he says, "with great violence against the floor of the laboratory, and dashed into a thousand pieces".

§ 214.

George Stephenson seems to have been the first to realise the essential identity of the quiet burning of an explosive mixture in an open vessel and the tempestuous burning of an explosive mixture in a vessel which burst under the strain of the pressures set up within it. In a partial enclosure, insufficiently vented, the burning is tempestuous almost from the outset. Now it was an old practice for the coal-mines to be cleared of methane by a "fireman". Hooded and cloaked, and bearing a torch

at the end of a long pole, he would crawl along the roadway testing the cavities in the roof with his torch, ready all the time to fling himself prone and let the flame of the explosion sweep along the roof above him. Flames in mixtures of methane and air that were only just ignitible would indeed move along above him, but the flame of a strongly explosive mixture would be far more likely to kill him. The whole adventure is reminiscent of that which was repeated to please Alexander in Ecbatana, as described in § 103.

Similar methods were evidently employed by our nearer continental neighbours. My friend, H. H. Oakley, has supplied me with a translated account of the getting of coal in the neighbourhood of Liège. He found the original in a text of the Camden Society. It was written in Greek by Nicander Nucius in the time of Henry the Eighth and supplied to the Venetian Senate with other official diplomatic documents perhaps equally accurate:

> "When the miners meet with this mineral—a stony substance, black and shining—they form a spacious Cavern, but they are not able to throw out the stones immediately for fire of a sudden bursts forth and encompasses the whole Cavern. When the miners desire to extract the Coal, they put on a linen garment which has neither been bleached nor dipped in water. This Covers them from head to foot, leaving only certain apertures for the Eyes; they also take a Staff in their hands, which serves to guide and direct their steps in the passage leading to the Cave. The miner then draws near to the fire and frightens it with his Staff. The fire then flies away and contracts itself by little and little; having then expended itself, it collects itself together in a surprising manner and, becoming very small, remains quite still in a corner. But it behoves the man who wears the linen garment to stand

over the flame when at rest, always terrifying it with his staff. Whilst he performs this service, the miners Extract the Stones; but as soon as they have left the Cave, the dormant fire on a sudden bursts forth and environs the whole Cave. This we ourselves have beheld. For we were desirous of ascertaining the fact by actual experience, being admirers of the operations of Nature, Etc."

In 1815, Stephenson was lighting these blowers of methane—not indeed as a fireman, for he was now enginewright at Killingworth—but with the desire of learning something about them in connection with his ambition of making a safety-lamp. The justification, if any be needed, of all such researches was once well stated by Paracelsus: "A physician must first know the disease with which he has to deal; when he knows this, the method of treatment will spontaneously unfold itself". Stephenson found, for example, that the burned gases would extinguish a candle. He noticed, too, that when firedamp was ignited, an appreciable length of time was necessary for the flame to travel from one point to another, and he thought that if a current of air could be produced in the opposite direction at the same speed, the flame might be held still. This was the principle of his "Tube and Slider" lamp, produced in the same year. The application of the principle was to control the speed of the draught in the lamp according to the explosibility of the atmosphere in which it was being employed. Thus "burned air" issued from the top of the lamp without igniting the explosive air outside, and the movement of the explosive air at the base was inwards. The only danger therefore was from the top of the lamp, and this danger, since only methane was concerned, was small.

§ 215.

Clearly Stephenson's principle of balancing is precisely what we have in the Bunsen burner with all its applications to cookers and radiators and laboratory heaters; and it is essentially the method used by Bunsen to determine the speed at which the reactive surface of flame moved through explosive mixtures of gases. The flame was kept still; what was measured was the speed of motion of the supply of mixture. The mixture was made and thoroughly mixed beforehand. Then it was supplied through a pipe to burn at an orifice. When the speed of the mixture was excessive, the flame was the familiar double cone of the Bunsen burner, kept still even now but not by an equality of speed. Equality of speed was obtained when the flame was reduced to a flat disc, just about to dart back through the supply pipe. Gouy evolved a method by which the desired datum could be determined from the angle of the inner cone and the rate of supply of the gas, and the only superficial objection to this method is that the cone is almost always geometrically imperfect.

An objection really fundamental was stated by Neyreneuf, and this objection throws its shadows over all empirical measurements of the speed at which a surface of flame moves through explosive mixture. He pointed out that on account of the expansion supervening on the ignition of gas, there is a backthrust into the burned gases. Ste. Claire Deville and Sir Dugald Clerk have said that the flame-surface itself is thrust forward by this expansion. The two effects must of course stand together, the one providing the "purchase" or "stretcher" for the other. The radiant shell of reactive gas is, indeed,

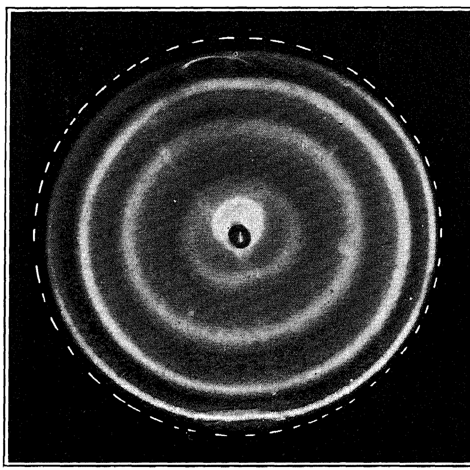
at a watershed of pressure, and in every gas-explosion there are these three phenomena, a wind travelling through the burned gases, a wind of opposite direction travelling through the unburned gases, and the radiant shell of luminous gas where the two winds stand back to back as they blow. To complete the description, we must imagine the flame-surface continually sloughing off a layer of expanding gas to the burned portion and seizing on a layer of unburned gas from the unburned portion. The simplest examples are afforded by the central ignition of explosive gas-mixtures in enclosed spaces which are compact, and the simplest of all occurs when we have central ignition in a sphere.

§ 216.

We may consider the contents of a spherical container as consisting of a nest of spherical shells arranged one inside the other like the thin wooden shells that fit one inside the other in the child's toy known as the Chinese Egg. If for a moment we neglect any gravitational effects (since these are important only when the mixture is feebly explosive) and ignite at a mathematical point at the centre, each shell throughout the explosion is a perfect spherical isobar. The radiant self-blown bubble is at any instant the surface of the spherical ball of hot gas, and it is just about to expand and become dim. The next layer inwards is expanding, pushing the bubble outwards and its inner neighbours inwards. The layer immediately outside the flame is being pushed outwards and it is transmitting this push to the layers beyond. It follows that while there is a sharp discontinuity of temperature, of pressure and of chemical identity between

GROWTH IN ORBEM.

" The simplest example of all occurs when we have central ignition of explosive gas-mixture in a sphere." (§ 215)



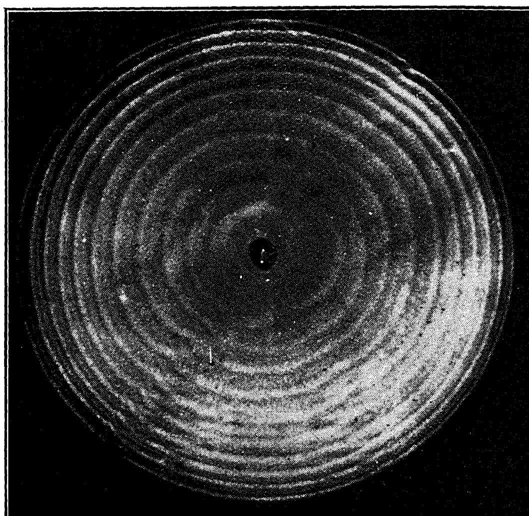
I.

Flame started at the centre of a hollow glass sphere, 9 cm. in diameter, containing a mixture ($13CO + O_2$) saturated with moisture at 17°C. Photographs were taken at intervals of 9·6 milliseconds.

[From a publication of the Safety in Mines Research Board, H.M. Stationery Office.]

GROWTH IN ORBEM.

"The simplest example of all occurs when we have central ignition of explosive gas-mixture in a sphere." (§ 215)

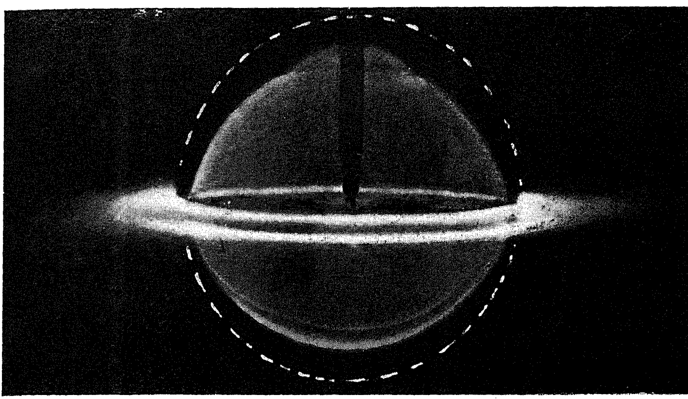


II.

More frequent exposures. This time, a photograph was taken every 2·05 milliseconds, and the mixture was ($10CO + O_2$) saturated with moisture at 10°C.

[From *Fuel in Science and Practice*, vol. 7 .1928

"THE RADIANT SELF-BLOWN BUBBLE." (§ 216)



III.

Flame started between two hemispherical glass shells (shown by dotted lines) each of 1200 cubic centimetres capacity, their rims being parted by a uniform distance of 1·25 centimetres. The upper shell has a flask-neck which served for the introduction of a glass-covered sparking-plug. The photograph was taken 72·22 milliseconds after the spark had passed. The explosive mixture contained 76% of air and 24% of carbon monoxide, and was fully saturated with moisture at 17°C. At the equator, the flame is passing as a thin circular sheet into the atmosphere.

[From *Transactions of the Institution of Mining Engineers*, vol. lxxx, 1930]

the unburned gas and the layer which is the flame-surface, there is no discontinuity within it, but a smooth, though rapid, grading. It may be noted that, before the inflammation is over, each layer has passed through three phases of existence; it has expanded in diameter under the compression of an expanding layer within it; it has been the luminous layer; and it has shrunk in diameter under the compression of an expanding layer outside it. Hooke once wrote: "All the Phaenomena of the Changes of Air in the great Ocean of the Atmosphere may be well represented in little". Here we have two divergent winds, back to back in a thimble!

§ 217.

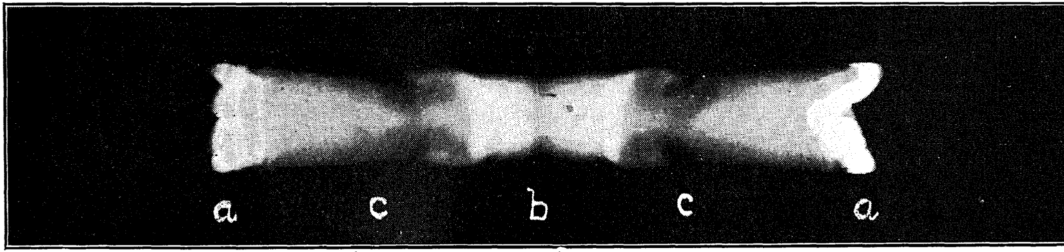
Now though *bubble* is the word which at once leaps to the mind of one who sees such a flame, or rather, perhaps, a snapshot of such a flame, it is a word that requires qualification. The bubble one thinks of is not the bubble of gas and vapour growing beneath the surface of a boiling liquid: that would be a very good analogy: but the soap-bubble. The radiant mask is not a hollow surface of constant composition, however, for it feeds and discards. Moreover there is no discontinuity between the flame-shell and its contents, whereas the inner surface of a soap-bubble is a discontinuity. This brings us to the remarkable fact that the comparatively dark gases in the interior of the flame do not cease to burn when they are sloughed inwards from the flame-surface. It is true that, when a layer of gas resigns its position as flame-surface and puts off its splendour, it loses heat by expansion and for a short time becomes almost non-luminous. But we have seen that

during the entire remainder of the explosion it is compressed. This in itself restores its temperature. It does something more. As the pressure rises, these burned gases are induced to continue a reaction, which is either chemical or electronic or both, sometimes with an intensity sufficient to be responsible for further light and heat. This phenomenon is called Afterburning. These gases, though no longer in the surface of the flame, are really burning and, if they are projected into explosive mixture under favourable circumstances, they will actually ignite it. They often emit a light, moreover, that is steel-white like the light of the flame-surface itself, not the reddish yellow sometimes seen in the expanding layers that lie immediately within the flame-surface.

§ 218.

Now, always supposing that the inflammation is so rapid that we need not consider the effect of gravitation, central ignition in a sphere is a condition where the speed of displacement is, at any moment, the same in every direction. When, for example, the flame has grown until it occupies half the capacity of the sphere and its surface moves with decreasing speed as more and more of the generated energy is applied inward upon the burned gases, yet the movement is symmetrical about any diameter. This is not true of any other condition, for even when we take some other symmetrical vessel and ignite at the centre in a strongly explosive mixture, it is no longer practical to ignore the effect of gravitation: inflammation is complete at the roof before it is complete at the floor.

"THIS PHENOMENON IS CALLED AFTERBURNING."

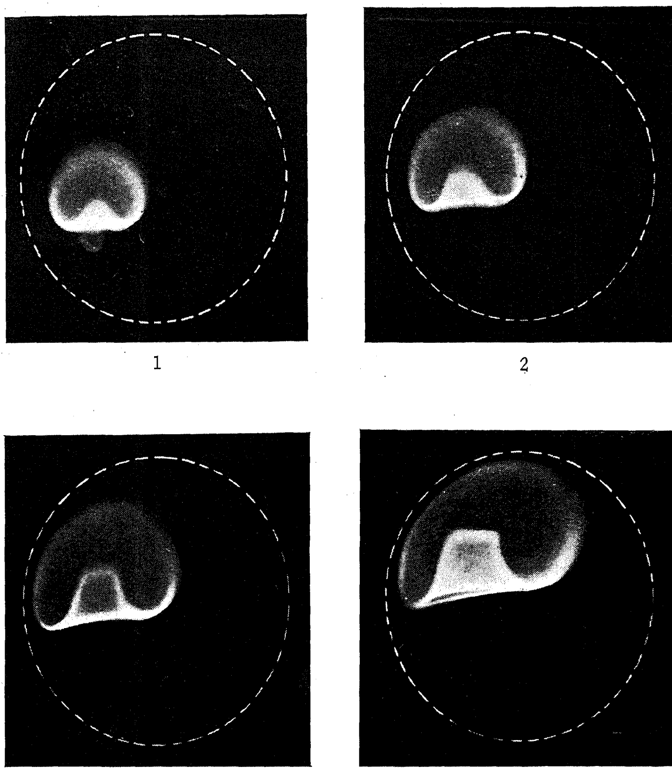


IV.

Flame started half-way along the axis of a closed glass tube set horizontally. It was 32 centimetres in length and 4 centimetres in diameter. The explosive mixture contained carbon monoxide and oxygen in the proportion of 2 to 5, and was fully saturated with moisture at 5°C. The photograph was taken 36·64 milliseconds after spark-ignition at the centre. The flame-surface has burned out at the roof and at the floor but is still spreading, left and right, at the two ends. It is marked (*a*.) The outward wind in the gas still unburned is not visible, but the inward wind through the flame-gases is semi-luminous, and is marked (*c*) It is spinning. The afterburning is marked (*b*).

[From *Fuel in Science and Practice*, vol. 7, 1928.]

The history of a feebly burning flame, asymmetrically ignited, determined jointly by its constitutional buoyancy (which raises it) and the pressure of its outward wind (which pushes it towards the centre).



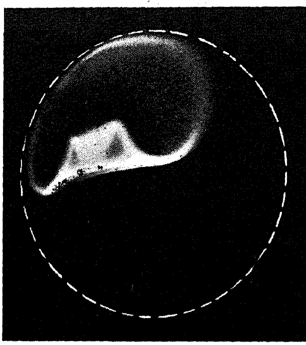
1 2 3 4

V.

Flame started in a mixture of carbon monoxide and air (13·15% CO), saturated with moisture at 15°C., contained in a sphere of 20 cm. diameter. Photographed 50 milliseconds after ignition and thenceforward at intervals of 20 milliseconds.

[From *Fuel in Science and Practice*, vol, 7, 1928.]

The history of a feebly burning flame, asymmetrically ignited, determined jointly by its constitutional buoyancy (which raises it) and the pressure of its outward wind (which pushes it towards the centre).



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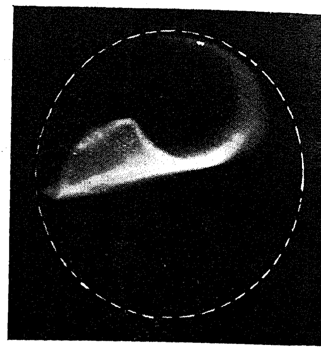

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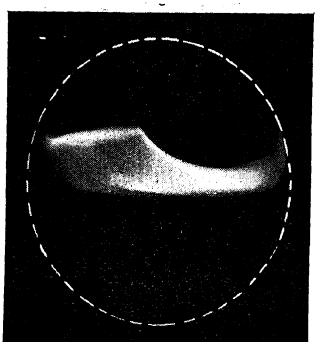

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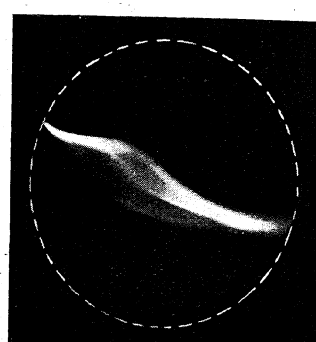

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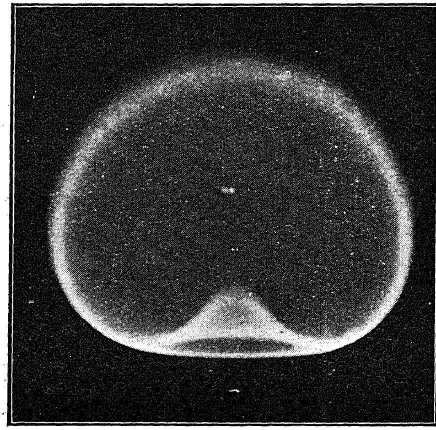
V.

[From *Fuel in Science and Practice*, vol. 7, 1928.]

"THEN THE FLAME DOES RISE CLEAR" (§ 219)



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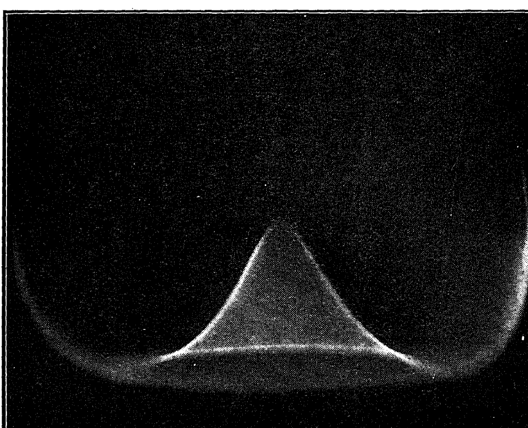
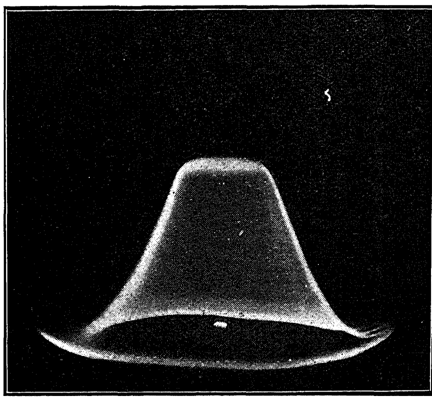


2

VI

[From *Fuel in Science and Practice*, vol. 7, 1928.]

"THEN THE FLAME DOES RISE CLEAR." (§ 219)



3

VI

The mixture was contained in a hollow glass sphere, 20 centimetres in diameter. It was 14% carbon monoxide and 86% air, and it was fully saturated with moisture at 12°C. Photographs were taken 272, 408 and 544 milliseconds after the ignition, which took place at the centre of the base. The flame rises, develops a spin, loses its upper surface and then burns only into the spinning vortex which is still luminous in the last picture.

[From *Fuel in Science and Practice*, vol. 7, 1928.]

§ 219.

The behaviour of the flame is primarily determined by the wind that blows from its surface in every direction through the unburned gas-mixture. Clearly, the flame must tend to centre itself in the enclosure, so that what matters is the lie of the wall of the enclosure considered as if from within the flame, the harbour-walls regarded from the boat. The flame-surface is still an isobar, and as all the isobars in the vessel move towards a position of symmetry and (if we arbitrarily limit their number) uniform spacing, they adapt their shape to the gas-space available. So also the flame-surface, merging into each layer, is shaped by the lie of the wall about it. A new factor enters as soon as the flame touches the wall, no matter where; for it must touch the wall sooner or later since it eats into the very gas with which it fends itself off. As soon as it touches, it is held. Just as a vapour-bubble is held to the wall below a liquid surface by the pressure exerted from every point of its common boundary with the liquid, and, in addition, by the condensation at the wall, so the flame is made to adhere to the wall of the gas-space.* This contact with the wall leads to a drain of heat, and much less energy is now available for the propulsion of the flame-surface in other directions. As a flame, touching the wall, adheres to it, so a flame started at the wall never, with one exception, is wrenched free of it. The exception involves ignition at the base of a vessel containing a mixture which is very weakly explosive. Then the flame does rise clear, and, as it moves upwards through the mixture, it develops a recess in its base which tends to be so shaped as to make any vertical chord of the flame

* See Plate IX, facing page 335.

equal to any other. Such flames are often beautiful examples of a spiral motion that seems inevitable whenever there is a motion of translation, and the recess at the base is usually a sharply defined vortex.

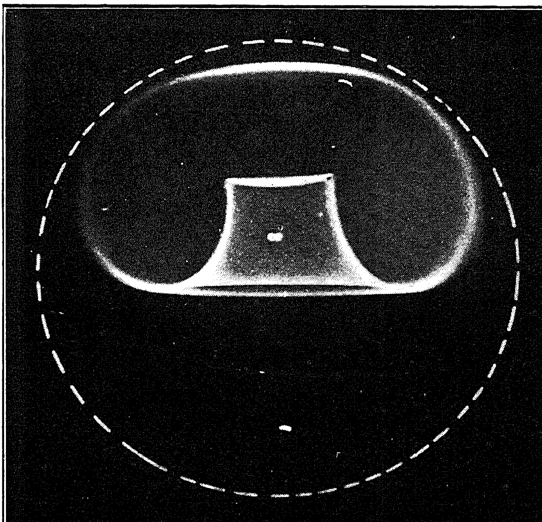
§ 220.

The conclusion that there existed a wind-movement in the unburned gas has been tested by two somewhat picturesque series of experiments. In the first, a number of flames were started in the wind by the simultaneous passage of sparks at different points in its course. The wind itself was that of a flame which was already proceeding along the uniform gallery in which the experiment was performed. It was found that the initial speed of the younger flames varied inversely as their distances from the single older flame. (This result makes it possible, by a simple proportion sum, to analyse the speed of spread of the older flame-surface into two components, the independent motion of the gas, and the speed at which the reaction is seizing upon it.) Another test was to arrange a number of simultaneous ignitions in an enclosed gas-space where each was the centre, so to say, of a region of influence, each region being symmetrical about its "central fire". What happened was that these regions behaved as if each were a separate gas-tight compartment. Yet there was nothing separating them except the dead calms at their boundaries. These calms are the meeting-places of the equal and opposing winds.

§ 221.

The shapes assumed by flames that grow in mixtures initially at rest in a closed gas-space are, as we have said,

"THE RECESS AT THE BASE IS USUALLY A SHARPLY DEFINED VORTEX." (§ 219)



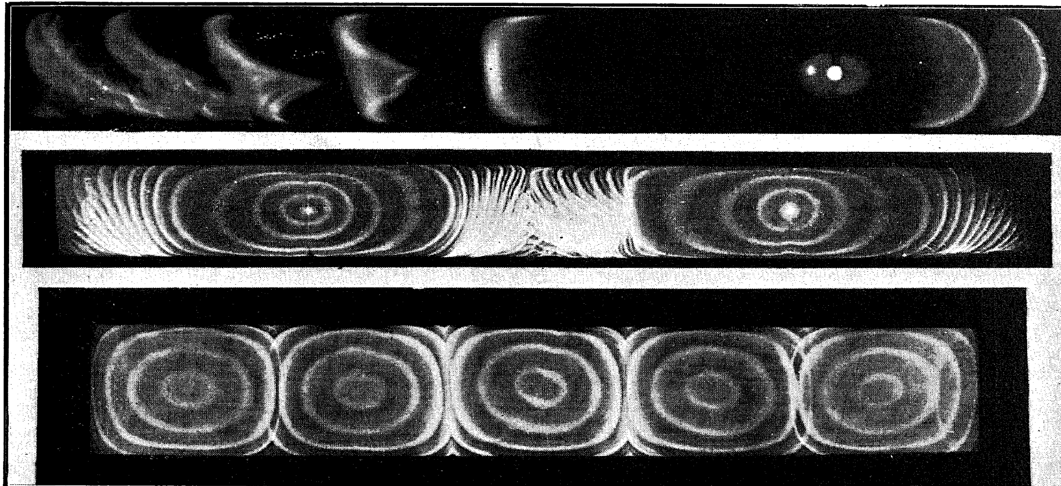
VII

This flame is burning feebly and has a much longer life than those on Plate VI. The shape of its vortex is characteristic of a more sluggish spin.

This flame was started at the base of a sphere, 20 cm. in diameter, containing a mixture of carbon monoxide and air (12·1% CO), saturated with moisture at 19°C. It was photographed 408 milliseconds later.

[From *Fuel in Science and Practice*, vol. 7, 1928.]

HOW FIVE FLAMES SHARED A COMPARTMENT. (§ 220)

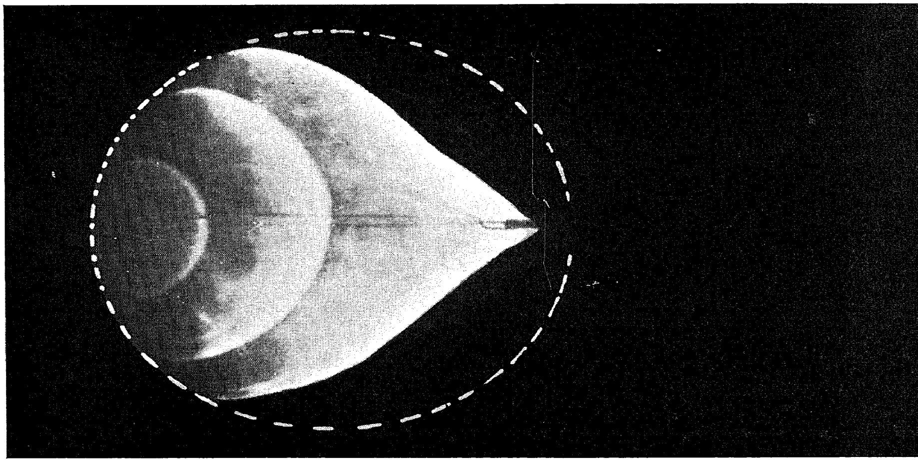


VIII

1. Single asymmetric ignition. Flame expires at the roof and floor but continues to propagate both ways laterally, centring itself in the tube. Six exposures.
2. Double Symmetric ignition (but one spark-gap a little wider than the other). The tube is partitioned by an impalpable central wall or pressure-meet. About sixteen exposures.
3. This explosion was arranged in a closed tube six centimetres in diameter and 30 centimetres in length. It was imagined to consist of five square cylinders of dimension six centimetres, and a sparking-point arranged at the centre of each of the imagined portions. Then the tube was filled with a mixture of carbon monoxide and oxygen, in the proportion of thirteen to one, fully saturated with moisture at 14°C. The five sparks were passed at the same instant. A flame started at each spark and the outward winds quickly set up three dead calms which actually partitioned the tube into five separate and equal shares. As the explosion proceeded, photographs were taken intermittently on the same plate at intervals of 9·63 milliseconds after ignition. The first, second and third, show five unbroken flame-surfaces; in the fourth, the flames have expired at the roof and the floor; the fifth photograph shows only the burning of small residues at the "partitions."

[From *Transactions of the Institution of Mining Engineers*, vol. lxxx. 19

"SO THE FLAME IS MADE TO ADHERE TO THE WALL OF THE GAS-SPACE." (§ 219)



IX

This set of three photographs also illustrates the statement in §221 that the flame-surface is a luminous isobar. They show three stages of an explosion started by a spark at the left wall of a glass sphere 14·5 centimetres in diameter. The mixture contained 43·5% carbon monoxide and 56·5% air, and was fully saturated with moisture at 19·5°C. The flame was photographed three times on the same plate, at intervals of 16·4 milliseconds after ignition, as it moved towards a circular vent, one centimetre in diameter, in the centre of the right wall. The third photograph shows how the isobars taper to the vent.

simply the shapes of the isobars made luminous, and therefore visible. If the mixture is already in motion when ignition occurs, the shape and motion of the flame again follows the isobars, the applied motion and the responding motion each modifying the other. For example, even in an enclosed gas-space, when ignition takes place at a heated wire, a convectional system is set up beforehand. Then the flame is drawn out vertically, as if influenced by a chimney, adopting indeed the shape commonly associated with "flame". Bacon's picture of the ordinary wick-fed flame should be interpreted with intelligent sympathy, and it serves very nearly for this free flame of ours also. He says: "The form of a pyramis in flame" is due to the "accident that the air about, by quenching the sides of the flame, crusheth it and extenuateth it into that form; for of itself, it would be round". In the nineteenth century, Frankland was to show that this wick-fed flame, relieved of a portion of atmospheric pressure, was indeed globular. Bacon had no suction-pump; he reached his conclusion by burning his candle within the much larger flame of some spirit of wine, burning in a porringer, and he noticed the tendency to rotation also.

§ 222.

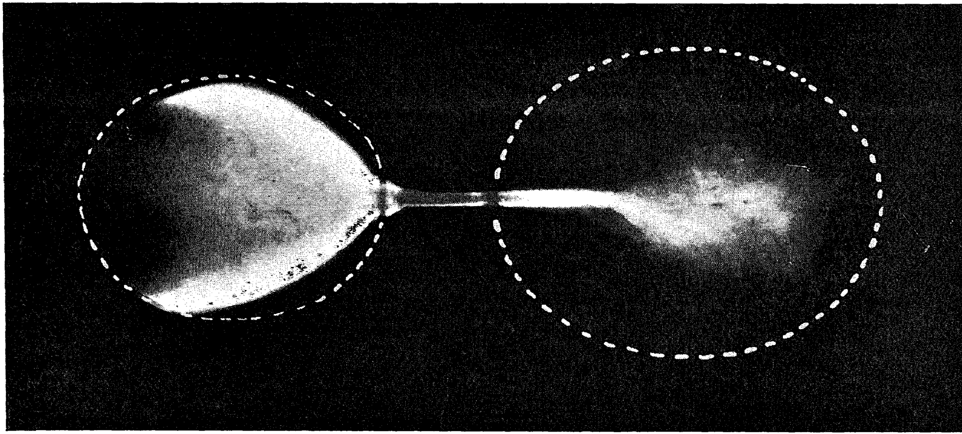
When the motion of the gas is violent, the contours of the isobars are so crumpled that we cannot sort them out. The gas is then in a condition which is commonly described as turbulence. When a fan is rotated in a mixture, the flame follows the swirling motion. If a jet of gas is propelled into the mixture at a high speed, the motions are even more chaotic. For example, if

such a jet of gas is expelled from one vessel into another through a communicating tube, and is then followed by the flame at whose surface its motion has been generated, the flame entering the second vessel is a formless spray. Now since every point on the flame-surface is a centre of ignition, the motion of the gas, by increasing the area of the flame-surface, has thereby increased the rate of combustion. That is why turbulence, or even a much smoother distortion of the flame-surface, shortens the period of inflammation. As Dugald Clerk has explained, it is because, in the cylinder of an internal combustion engine, the flame starts in a wind-storm that the inflammation is sufficiently rapid to make the automobile possible. The charge enters the cylinder, on the heels of the piston, in a misty jet from the carburettor. It is turbulent, and the flame that spreads through it is turbulent. This has an important application in the construction of casings for electrical appliances underground.

§ 223.

When flame starts in a partial enclosure, it is governed partly by the consideration already stated and partly by the new condition. In this brief summary we need mention only those associated with the existence of the vent. The three possibilities are ignition at the vent, ignition at some point within the gas-space, and ignition at some position in the interior wall. Ignition at the vent is, in principle, the experiment suggested by Bacon, the modern equivalent of which would be to "light a match and see if there's any petrol left". Because there is combustion within the enclosure, the flow from the vessel starts without delay, and the flame burns into it, a radiant

"CRUMPLING THE ISOBARS."

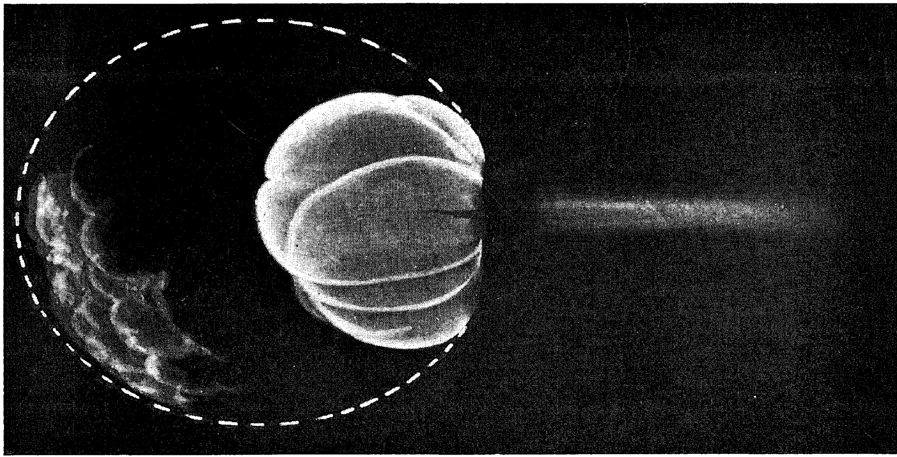


X

Flame started at the left wall of the smaller of two spherical glass shells, joined by a glass tunnel. The capacities are 250 and 500 cubic centimetres respectively, and the diameters 4 and 5 centimetres. They contained an explosive mixture consisting of 25% carbon monoxide and 75% air, fully saturated with moisture at 18°C. The photograph was taken 73 milliseconds after ignition. The flame is entering the second vessel (where the contours of the isobars are so crumpled that we cannot sort them out) as a formless spray.

[From *Transactions of the Institution of Mining Engineers*, vol. lxxx, 1930

"A LUMINOUS MASK, BEAUTIFULLY CREASED AND FLUTED." (§ 223)

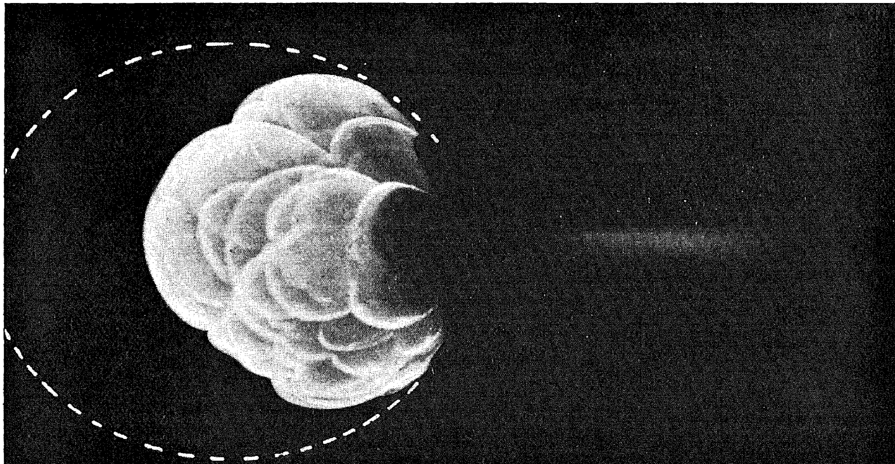


XI

The title refers to the flame which is entering the glass sphere at the vent in the right side. Expelled gas takes fire at the vent and streams into the atmosphere. This photograph was taken 19 milliseconds after an explosive mixture containing 33·5% carbon monoxide and 66·5% air (fully saturated with moisture at 19·5°C.) had been ignited by a spark just inside the vent. The subsiding foam of flame on the left of the shell is a second photograph taken 135 milliseconds later.
Diameters: Sphere, 14·5 centimetres; vent, 1·25 centimetres.

[From *Transactions of the Institution of Mining Engineers*, vol. lxxx, 1930.]

"THE DISTORTED FLAME RESEMBLES A MASS OF BUBBLES." (§ 223)



XII

Here, there is one photograph only. It was taken after the force of the explosion had blown off a piece of adhesive tape which had been placed lightly over the vent, but only 16·4 milliseconds after ignition. The mixture was a little different, the percentage of carbon monoxide here being 44·5.

[From *Transactions of the Institution of Mining Engineers*, vol. lxxx, 1930]

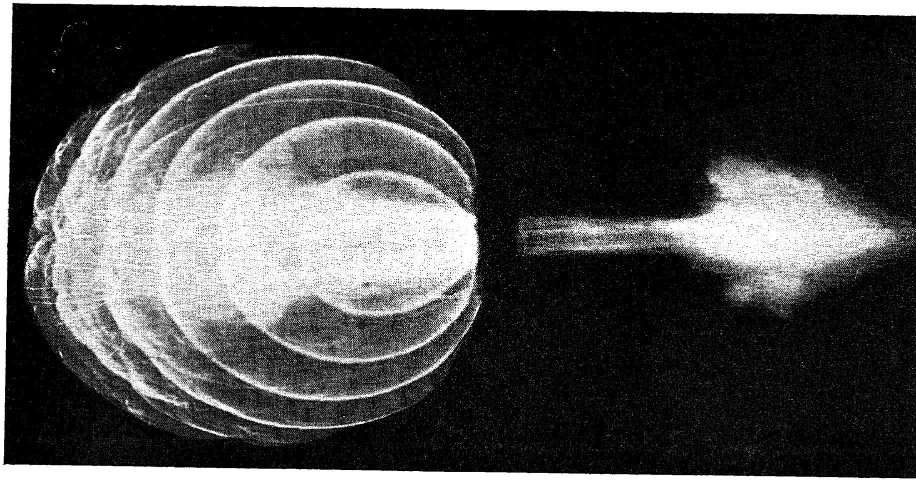
mask beautifully creased and fluted down its sides towards the vent where the surrounding gas moves outward, little, however, escaping at the periphery of the vent without being kindled—though the inflammation is not finished there, for the flame streams out into the atmosphere. As the distorted flame in the interior increases in area, the flow increases, each influence intensifying the other, until, very soon, the flame resembles the mass of bubbles obtained when a child blows into a pipe, holding the bowl below the surface of a mixture of glycerine and soapy water. A moment comes, however, when there is a great reduction in the area of this interior flame-surface, since much of it has burned out on the interior wall. After this, therefore, it propagates with less disturbance, although, right to the end, the surface is cobbled and quite dissimilar from the smooth shell of a flame propagating in a small gas-space that is entirely enclosed. It will be clear that a great part of this disturbance is due to the relative smallness of the vent.

§ 224.

Keeping the vent the same size, and reducing the vessel to a long tube of the same diameter as the vent, we increase the duration and the tranquillity of the initial burning, during which the shape and speed of displacement of the flame-surface are uniform; although the gas-mixture is flowing (gently) in the opposite direction, as before. The uniformity of the speed of displacement of the flame-surface during this period has made it a favourite subject of research. It is particularly associated with the names of Davy, Mallard and Le Chatelier, and Wheeler. The numerical values obtained are

in close agreement with those of Bunsen and of Gouy; for, when the inner cone of a Bunsen flame begins to travel down the burner to the position known as "burning back", the two phenomena are almost identical. The identity is complete when the length, diameter and orientation of two tubes are the same. The speed of displacement of a flame-surface entering such a tube is less for less diameters, a result bound up in Davy's discovery that, under atmospheric pressure, flame would not enter and propagate itself in a tube of less than a certain minimum diameter (a discovery which must necessarily be qualified in speaking of certain gas-mixtures, such as, for example, electrolytic gas). It is clear that if we adopt a standard length, diameter and orientation of the tube, the initial speed at which flame enters it from the atmosphere will be specific to the mixture it contains. Mallard and Le Chatelier evolved a formula for this speed, and this formula may be used in a rough comparison of one mixture with another. Payman and Wheeler have shown how this speed may be correctly calculated for an untested mixture if the constituents of the mixture are known. The method explains a deduction of Mallard and Le Chatelier which enables us to calculate the Dilution Limits of Inflammability of a mixture of fuels, provided these limits are known for each of the constituents of the mixture. The expression refers to the two percentages of fuel in mixtures with air, between which all mixtures are explosive. Mason and Wheeler have shown that the further history of the flame after this quiet entry into the tube is governed by the acoustics of the tube; and other investigators associated with Wheeler, also as his assistants in the Safety in Mines

"THE VESSEL COUGHS."



XIII

Six snapshots, taken every 16·4 milliseconds after ignition, of a flame started in the vented sphere described in Plate XI, one quarter of a diameter from the vent (1·25 cm. in diameter.) The mixture was one of carbon monoxide and air (63·5% CO), saturated with moisture at 17°C.

[From *Transactions of the Institution of Mining Engineers*, vol. lxxx, 1930.]

Research Board, have continued this examination of the flame's behaviour.

§ 225.

When ignition occurs in the gas-space of a vented vessel the flame grows normally until the outflow becomes considerable. Then it moves towards the vent. The isobars taper towards the vent. So therefore does the flame, and this means a somewhat sudden increase in the area of its surface. This intensifies the outflow which again intensifies the rate of the increase in area. These two mutually supporting factors are the cause of what is probably the most violent expulsion of flame in all such experimental arrangements. The vessel "coughs" and the expelled shaft of flame is rippled by stationary sound-waves. Even so, an external explosive-mixture is less liable to be ignited by the outflowing flame than when the ignition was at the vent, because the duration of the expelled flame is less. The fact was demonstrated by Beyling.

§ 226.

Beyling also demonstrated that the position of the internal ignition for the least likelihood of external ignition, other things being equal, was in the wall opposite to the vent. Photographs show that nearly all the explosive mixture is expelled ahead of the flame. The flame bases itself on the wall and tapers to the vent with the other isobars; but once it has issued, there is very little reserve of gas to maintain it so that though the external atmosphere may be explosive it does not always ignite. Beyling hoped at one time to be able to apply this discovery to the construction of casings for

electrical appliances in dangerous atmospheres, but found that this was not practicable. To be safe, an appliance must be safe for all possible mixtures of the fuel with air. This was not safe for weakly explosive mixtures.

§ 227.

The actual incursion of flame into a highly explosive mixture without a consequent ignition does, however, call at this point for some comment. It is due to what Mallard and Le Chatelier termed "le retard à l'inflammation" and Wheeler "the lag on ignition". That there is such a quantity follows from the fact that explosions are not instantaneous. That it varies follows from the fact that different mixtures fired under strictly similar conditions, exhibit flame-surfaces travelling at different speeds. It is not only specific to the explosive mixture however. It is determined by two other contributory factors, the source of ignition and the time during which this source is applied. For example, in the Barnett Igniting Cock where the charge in the cylinder was ignited by the flippant entry of a flame through a periodic congruence of apertures, a too speedy revolution of the plug would cause a misfire.

§ 228.

Similarly in Newton's Engine a hot place in the wall of the cylinder was briefly touched by the charge, but not too briefly. Now, if a standard lag-period be adopted, then the temperature to which gases must be brought before they will inflame within this period is a measure of their inflammability. This is the principle of the "Concentric Tube Method" of Dixon and Foster. The

notion of "lag" is, however, perhaps most picturesquely exemplified by the ordinary spark of the concussive method of ignition. Such sparks do not remain hot long enough to ignite explosive mixtures of methane and air; and up to the time of safe hand-lamps (1816), flint-and-steel mills, hand-turned, provided the working illumination in coal mines. Mixtures of hydrogen and air, however, may be ignited by these sparks; and Volta in 1777 concluded that this was true also of the inflammable air native to marshes. Frankland found that these sparks ignited hydrogen, carbon monoxide, and mixtures of coal-gas with air. "These results", he says, "are quite in conformity with the experience of gas-engineers and managers, several letters from whom are now before me, describing the ignition of gas from the sparks elicited by the contact of workmen's pickaxes with stones, the chipping of a main, etc. The notion that coal-gas will not ignite under these circumstances has doubtless arisen from the impossibility of so igniting the gas of coal-mines", but he points out that the combustible gas existing in coal-mines has been proved by very numerous analyses to be methane only—no trace of hydrogen, carbonic oxide or olefiant gas being ever present in it. "Hence, whilst a mine may be safely lighted by the 'steel mill', the use of such an instrument in an explosive mixture of coal-gas would infallibly cause ignition". These conclusions are supported by the results of many researches by later investigators. The work of Burgess indicates that laboratory examinations of the subject have generally involved the possibility of ignition by the gradually heated surface of the grinding blocks producing the sparks.

§ 229.

There is no lag on ignition when ignition is due to a single electric spark. The ignition is Yes or No. Also, chiefly from the researches of Coward and of Wheeler, it has been shown that

i. For any mixture, the other experimental conditions being rigidly the same, there is a minimum pressure at which ignition is possible.
ii. The other experimental conditions being rigidly the same, there is an optimum width of spark-gap.
iii. The other experimental conditions being rigidly the same, there is a minimum igniting current.
iv. The proportion of fuel varying in a series of mixtures with air, the minimum igniting current decreases smoothly to a minimum for the most readily ignitible mixture, and then increases as the proportion of fuel increases.

This is an attractive comparison of ignitibilities since there is no oxidation of the source of ignition, nor any pre-flame combustion.

The best criterion of inflammability, therefore, that can be found is implicit in a method of ignition where there is no lag whatever. If we employ a standard container having a pair of permanent electrodes, their points a permanent width apart, and carry out all our experiments at the same temperature and pressure, then the minimum igniting current is a measure of the ignitibility of the explosive mixture which we test. It is a criterion that may be applied to any mixture of air (or oxygen) with a gas or vapour, with one class of exceptions. This class has inflammabilities which depend on the proportion of moisture present. The only members

of this class, so far as we know at present, are mixtures of air (or oxygen) with carbon monoxide. These also may be admitted, however, provided that in referring to them, we always mention the proportion of moisture, or other hydrogen compound, that is present in their composition. This method then, applied principally by Wheeler and by Thornton, enables us to compare the inflammabilities of explosive mixtures of gases: thus we can say that a 7.5% mixture of methane is more inflammable than a 7.5% mixture of propane: but it also enables us to compare the inflammabilities of the fuels themselves, for the most easily inflammable mixture of propane is much more easily inflammable than the most easily inflammable mixture of methane; and a very weak hydrogen mixture is much more easily inflammable than any methane mixture. If we except solids and non-volatile liquids from our investigations, therefore, here is the criterion we have sought.

In this method, what has happened to that principle which, in other methods, is manifested as the "lag on ignition"? Wheeler has shown that when the "igniting current" is just too small, the spark causes a momentary flame, diamond in section, which dies at birth. The flame does not take up a separate existence, independent of the spark-energy, unless it is endowed at birth with enough energy to reach a minimum volume. Below this minimum volume, it is chilled by the electrodes. At this minimum volume, combustion proceeds over its now sufficiently large surface. It would appear that the exact size of this minimum volume will vary with the identity of the explosive mixture. Measurements of this kind naturally call for methods of the utmost delicacy. For

example, there must be no sputtering of metal particles across the spark-gap. The metal must be platinum.

One of the first explanations of the electric spark ignition may read strangely to us nowadays, for we attempt to explain everything in terms of electricity. The explanation was due to Biot, who, as we have seen, blew up an air-gun by using it to compress electrolytic gas. The gas had come from water. It had been compressed, and it had gone back to water. The chemical union was due to the compression, and this similarly was the mode of operation of the electric spark. Berthollet was inclined to agree with this, but Humboldt and Gay Lussac attributed the union rather to the high temperature produced. That they were right was demonstrated by Davy, who showed that when explosive mixtures were compressed slowly there was no chemical action. A hundred years later, Nernst suggested that the relative ignition temperatures of explosive gas-mixtures might be determined from a compression method, and this principle was adopted in methods due to Falk and to Dixon. The temperature obtained when the explosive mixture was suddenly compressed with the smallest compression ratio yielding ignition was calculated from the formula

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma - 1}$$

in which T_1 and T_2 are the absolute temperatures of the mixture before and after the compression, V_1 and V_2 the initial and final volumes, and γ has its usual significance, being the ratio between the average specific heat of the explosive mixture free to expand with its rise of temperature ("constant pressure"), and its other specific heat,

a smaller quantity, in circumstances where it is not free to expand and remains therefore at "constant volume". These two determinations of the specific heat of any gas or gas mixture are usually written C_p and C_v

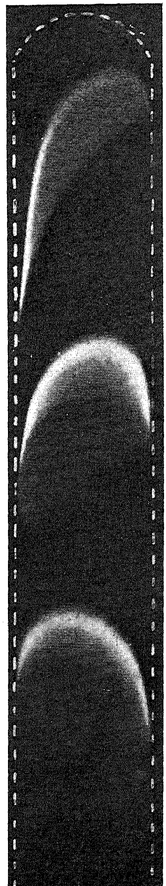
§ 230.

All matters affecting ignition are reflected in the rate of propagation. Factors tending to assist or to inhibit the one will tend to have a similar effect on the other. The dilution-limits of inflammability are thus widened by a rise in temperature, and narrowed by a rise in the initial pressure. It is important not to confuse this effect of increased pressure with either of two others, namely, the increased difficulty in passing a spark and the increased strength of the spark when passed. In propagation, the lag on ignition is reduced to its simplest and ideal form, for we conceive of propagation as being the ignition of a layer of explosive gas by its luminous neighbour. Clearly the ideal lag is closely related to the speed at which the radiant reaction would move through the mixture if the mixture could be kept still. Also, just as ignition may supervene on sudden compression, so propagation may depend on the transmission of a sudden compression from one layer upon its neighbour. Then the propagation has the speed of sound. This was recognised by Mallard and Le Chatelier and demonstrated by Dixon. It occurs when the high pressure in the unexpanded flame-surface passes a critical point; until then, the propagation has the normal features that have been described. Thereafter the outward wind and the flame-surface travel with the speed of sound, and, together, are named the Detonation Wave. The inward

wind travels with the speed of sound also and is called the Retonation Wave. Mallard and Le Chatelier conceived that the wind and the flame might be separated so that a new flame ahead of the old one might be created simply by the rise in pressure. Campbell has demonstrated how this may happen, and he has shown, with his associates, that the flame commonly moves in a spiral. This recalls a discovery of W. A. Kirkby that in some gas-mixtures the flame might travel with either of two speeds. These papers are required to complete the beautiful survey of the behaviour of detonation-flames that was published by Dixon.

§ 231.

In gunpowder we have a model in the solid state of an explosive mixture of gases, nitre being substituted for air, and sulphur and carbon for the gaseous fuel. Its force is in the sudden production of gas in a partial or complete enclosure. High explosives are the solid analogues of gaseous mixtures that detonate. Their principle is the combustion of a molecule in its own oxygen. Thus tri-nitro-toluene $C_7H_5N_3O_6$ contains in itself both combustible and comburent. Other largely non-gaseous explosions have occurred in sulphur mills, sugar factories and coal-mines. The majority of combustible substances which are not completely oxidised will explode under suitable conditions, when finely powdered and raised in suspension in air. Ignitibility varies widely. Some dust-clouds may be ignited by an electric spark, while others require a flame. As with a gas-mixture, there is an upper and a lower limit of



XIV

Flame Turning and Twisting in its climb towards the roof of a tube, 5 cm. in diameter, open at the base, containing a mixture of carbon monoxide and air (44% CO) saturated with moisture at 17°C. The intervals between the photographs are each 143 milliseconds.

[From *Transactions of the Institution of Mining Engineers*, vol. lxxx, 1930.]

concentration which confine inflammability to the intermediate range. Similarly, there is a pessimum concentration at which the most violent explosion occurs. Inflammability varies also with the fineness of the dust, since this is a measure of the surface exposed to oxidation. The inflammability of coal is influenced also by its content of volatile matter, ash and moisture. There is a decided tendency for it to increase as the percentage of volatile matter increases. The relative ease of evolution of inflammable gases has been suggested as an important factor, but recent work tends to show that inflammation is dependent rather on the ease of oxidation of the coal than on the distillation of gases. The inflammability of coal-dust is considerably reduced if the ash content be larger or if stone-dust is raised into the atmosphere with it; hence the well-known method for preventing coal-dust explosions. Moisture raises the temperature of ignition, thus reducing the inflammability, in proportion to its amount.

§ 232.

No phenomenon nowadays can be considered as completely explained in terms of molecular behaviour, however, or even of atomic behaviour. The mention of moisture recalls the outstanding example of the inadequacy of such treatment. The well-known use of water in brightening the fire of coke or charcoal has many cognates in the laboratory, but we do not now go so far as to say with Mrs. Fulhame that "Water is decomposed in every instance of combustion". The presence of water-vapour is indeed of powerful assistance in many chemical reactions. It may act as a

comburent in a gaseous analogue of the thermit process, but often its action is less easily explained. Thus, while dry hydrogen and dry chlorine will not combine even in sunlight, the same gases will unite with violence under the action of a much less powerful irradiation when moisture is present. It is not satisfactory to say that there are two reactions, the water first reacting with the chlorine. Similarly, carbon will burn more easily in moist air than in dry, and a flaming jet of carbon monoxide is extinguished when introduced into a dry atmosphere, whether of air or of oxygen. There are two reactions, some part of the carbon monoxide first uniting with the water-vapour, but there is a portion of the carbon monoxide for the combustion of which an alternative explanation must be found, and this explanation must deal with things smaller than atoms. The explanation, then, is electrical. The water molecule is not a symmetrical arrangement of two twin hydrogen atoms in leading strings to an atom of oxygen. The oxygen shows a vacillating preference, so that we have at any moment

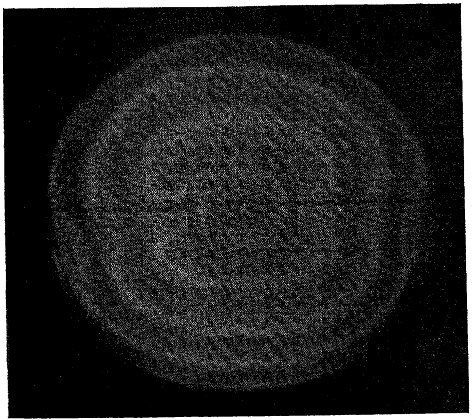
water = hydrogen hydroxide, a "salt"!

$H_2O = H.OH.$

When hydrogen and oxygen combine and form water there is a re-distribution of electrons round the nuclei of the atoms, and the effect of this re-distribution is that the hydrogen end of the water-molecule is positively charged. The hydroxyl end is negatively charged. Thus the water-molecule is "polar".

During the production of a chemical compound from two mutually reactive gases, complexes may form which contain molecules of both in close proximity. With electrically neutral molecules this may not be possible,

"FLAME AND THE FIREGHOST."



I.

Photographs, every 19·26 milliseconds, of the spread of a flame from the centre of a sphere 9 cm. in dia. The mixture was made up as follows:—92·2% CO, 6·8% O_2, 1·0% H_2. The flame is symmetrically distorted owing to the presence of two metal discs and their supports, symmetrically placed 2 cm. apart.

The diameter of these discs was 1·5 cm.

II.

Repetition of the experiment when the gas-mixture between the discs was subjected to a strain of 3,000 volts per centimetre. The flame leaps to the negative electrode, and its later history is governed by the asymmetrical position it has thus assumed.

XV.

[From the *Journal of the Chemical Society* (Guénault and Wheeler) 1931.]

but usually ions are present, and complex ions may be formed. Ions are normally present in all gases. The negative ion is an electron that has lost its orbit round the atomic centre. The positive ion is an atom that has lost a planet. One of the most fruitful ways of producing ions is to ignite an explosive mixture of gases. The ionisation proceeds in the flame-surface and the ions largely re-combine in fresh arrangements behind it From their nature the positive ions are more massy than the electrons so that when the flame moves through a region of electrical strain between two oppositely charged poles it behaves as a positively charged body and is attracted at the negative pole. This has been recently demonstrated by Guénault and Wheeler. A similar production of complexes may occur if polar molecules are introduced to the mixture of the two gases. This is most easily done by adding moisture. It is the old alliance of Fire with its dearest enemy.

§ 232 *bis*.

A NOTE ON MODERN METHODS OF FLAME PHOTOGRAPHY.

CONTINUOUS DIRECT REGISTRATION.

This method was invented by Mallard and Le Chatelier. It consists of wrapping a length of sensitised paper or film on a drum; then the light emitted by the flame of the explosion is focussed through a window on to the drum, which is rotated at a predetermined rate. Modern gearing and modern photographic facilities have made possible the most exquisite refinements of this method. Examples may be consulted in the *Journal of the Chemical Society* in the papers of Campbell, Kirkby, Ellis and Wheeler and others, or in *Fuel in Science and*

Practice, particularly the volume for 1928. The best sensitised medium in the author's own experience is *Ilford Recorder* 5119—1G.

SPARK PHOTOGRAPHY.

Two methods of spark photography are available, the shadow method of Dvorák, and the Schlieren method of Töpler. Both depend upon the fact that a ray of light on passing through the atmosphere is deflected by pressure differences. The sensitive material does not receive focussed light from the flame of the explosion, but is acted upon by a beam of light across which the flame passes, giving a kind of shadow. It has been applied to the photography of flames and sound and shock waves by Payman and Robinson.

CONTINUOUS SHADOW AND SCHLIEREN REGISTRATION.

A method of obtaining timed and continuous records by the shadow and Schlieren methods has been devised by Payman and Shepherd. A description of the methods is given in a paper in the *Journal of the Chemical Society* in 1928, and examples may be consulted in papers by these authors in the *Proceedings of the Royal Society* and in the publications of the *Safety in Mines Research Board,* and by White in the *Journal of the Chemical Society.* A modification of the method by Ellis and Morgan makes possible an assessment of the temperature gradient within the flame gases.

SNAPSHOT DIRECT PHOTOGRAPHY.

Snapshots of very slowly moving flames were obtained by Coward and Brinsley in 1914. Mason and Wheeler obtained pictures of flames moving at a uniform speed by focussing them on to uniformly moving paper. The method employed by the author in obtaining the illustrations to the present volume derives from Bunsen or from Marey who both rotated slotted discs between the object and the inspection position. They

lacked the resources of electricity and photography that are now available however. The flame-pictures in this book are all of carbon monoxide explosions and were taken on the fastest Ilford plates. F. J. Hartwell finds that the new Ilford Hypersensitive Panchromatic plates will produce equally good photographs of methane-air explosions in quite small explosion vessels.

CHAPTER XI.

RETURNING DAWN.

Canst thou bind the Unicorn in the furrows?
—*The Book of Job.*

Cease your work, ye maids who have laboured at the mills. Sleep, and let the birds sing in returning Dawn; for Demeter has called the water-nymphs to do your task.
—*Greek Epigram.*

Water shall be raised up for him. He shall be transported to every place where he desireth to be.
—*Pyramid Text of Pepi.*

What appears beyond hope emerges wonderfully into truth. . . . The ultimate matter is in Water. . . . So that from Water, Fire should issue forth. It is beyond the reach of Man's intelligence: it is not beyond the power of Nature.
—*Paracelsus.*

I asked her, Lady, why is the tower built upon Water? She replied, Because your life is and shall be saved by Water. And I answering said unto her, But, Lady, who are those young men that build?
—*Third Vision of Hermas.*

§ 233.

Boulton, the partner of James Watt, being asked by Johnson's toady what he sold, astounded him by replying "Power!" Yet there are countries in which water is sold and where land is a mere commodity; the price of raw material can never be less than the labour of its collection, and, free as power may be, it is after a long and painful history that mankind is beginning to learn how to collect it. The enormous energy of the tides and of the Water Cycle which supplies the rush of streams, the blowing of winds and the growth of food, spine and muscle, will

always for the most part run to waste, but to an increasing extent we can employ it; and though, with the departure of leisure, the primitive uses of free power were abandoned for the more immediately fruitful methods which darkened heaven and made desolate the face of the earth, this very vice of progress has taught us to return to the cleanly cosmic power equipped to use it more fully.

§ 234.

The history of mankind's lessoning in the use of power is quite unaffected by the question of how far the Magi were ahead of their contemporaries in respect of their mechanical secrets. Even granting the astonishing claim of Eliphas Lévi that "It is certain that the Magi were not only familiar with electricity but were able to generate and direct it in ways that are now unknown", and accepting with delight the story that "Numa directed his battery with success against a monster named Volta, which was ravaging the district about Rome", these men were manifestly impotent to generate it and direct it in ways that are now known; and their knowledge, if any, stands outside the stream of racial development as effectually as the piety of a hermit preserves its purity from the grossness of the pariah mob.

They had one important stage of development in common—a regard for the useful properties of the circle. In the Ethiopian *Book of Enoch,* we find that the turning of the sky was due to certain winds; and we have already noted a general tendency to regard winds as born in the clouds. When the early agriculturists employed a mill for grinding corn, therefore, there arose, as for example,

among the Chinese, and among the Norse, the myth that the sky was turned by the nine giant daughters of the clouds (for it was the women who ground) who paced the outermost causeway of the World. The North Star was the nail or spike about which the great wheel turned. We need look no further for the rolling disc. Then there was its first cousin, the cylinder. The most ancient methods of transporting over land the huge masses employed in early monuments was to roll them, trussed on a sledge, upon the trunks of palm-trees repeatedly placed in front, while levers helped behind. Two of the developments of the lever were the pivoted arm of the balance and the pivoted door of prehistoric Babylon: for the Medes were great engineers; they drained and bridged and tunnelled. The cylindrical log developed on the one hand into the spindle (when sewing with sinews gave way to sewing with thread) and on the other hand into the disc or wheel. On the one hand the child gained a whipping-top, on the other a hoop. The pivot and the disc gave birth to the chariot and to the wheel of the potter.

The recent excavations at "Ur of the Chaldees" show that in that neighbourhood the pre-deluge potters used no wheel. In Egypt it was also unknown in the earliest dynasties, but it is found in later representations of the creative acts of Ptah, Tatenn and Khnemu; Mycenæan pottery was made on the wheel, and the instrument was familiar to Homer. Between the fourth and the twelfth dynasties, the pyramids arose. Petrie tells us that among the tools employed was the bronze saw. If we imagine this thickened, as we imagined the log attenuated to a disc, we have the rack. The screw

was the simple spiral road up which Man climbs to subdue *all* his mountains.

Contemporary with the bronze saw itself was its adaptation from the straight form to the circular form of a tubular drill. The end of this drill was immediately the forerunner of the pinion, the ratchet, and all the other forms of toothed wheel. The saws and drills of these builders were coeval with the earliest lathes. Drill and lathe equally were turned by the pull of cord on spindle, and hence developed at last the various systems of pulley-blocks and differential axles. A draw-well with a pulley is to be seen in the Assyrian sculptures. Tylor thinks that from the pulley arose the European saying that "the sun is drawing up water" when his beams descend through distant cloud-spaces, and the reader must choose between this theory and the explanation inherent in § 172 of the present volume. It may be added, however, that Virgil speaks even of the Rainbow as drinking deeply of water.

§ 235.

These mechanical advances were not continuous, and knowledge was often lost over spans of centuries, sometimes, it may be, for ever. A peak was reached in the time of Archimedes of Syracuse and Ctesibius of Alexandria. They used the endless screw, there were screw linen-presses and oil-presses, and delicate screw adjustments on complicated instruments were employed by contemporary surveyors and astronomers. A science of practical pneumatics was born, and there were heavy "guns", worked partly by compressed air. Part of the *Mechanics* of Ctesibius' pupil, Philo of Byzantium, is

still extant. Here is explained the construction of automata, the theory of the lever, and an experimental determination of the density of the air. All sorts of mechanical toys are described, with diagrams, besides a censer worked by steam, the water-wheel, a water-engine, and an automatic slot-machine for providing lustral water at the entrances of temples. Philo was conversant with the syphon, and used atmospheric pressure for most of his devices.

§ 236.

After "the cold breath of Rome" had brought desolation both to the inventor and to the speculative philosopher, Vitruvius in the first century B.C. republished some of the work of Ctesibius; this included the famous water-clock, the principle of which was that the rise of water in a tank raised a float whose mast-like axle was toothed along the edge, engaging with a cogged disc carrying a pointer : it was assumed that the water dripped into the tank at a constant rate. Many other inventions of Ctesibius and Philo were published two hundred years later still by Hero of Alexandria, who hence has erroneously been credited with the authorship of a type of steam turbine; he built a spherical vessel, pivoted on a central axis, which rotated as the steam escaped through bent pipes opening at the periphery.

§ 237.

It will be observed, however, that progress was almost all along the line of applying the power, which was assumed available. When the political identity of Greece was broken, manpower was translated into the languages of Rome and of the East as slave-labour. Thus

the Roman crane was worked from a spoked wheel used as a "treadmill". One such, a very late model made in the fourteenth century, is still (1931) in use at Danzig. Among the copious illustrations in *De Re Metallica,* Agricola depicts treadmills worked by a horse (with his head in a fodder-basket) or by a pair of goats.

With the inrush of the blue-eyed Northerners, even the poor knowledge of the Romans was submerged. Boëthius, halfway through the sixth century, rediscovered the water-clock, but Boëthius was executed. Gerbert, an eminent ecclesiastic known also as Sylvester II, who died in 1003, constructed at Rheims, according to William of Malmesbury, such wonderful hydraulic machines that the water itself executed symphonies and played most enchanting airs. He adorned the town of Magdeburg with a clock which registered all the motions of heaven and the times when the stars rose and set. But it was believed that this pope had infallibly sold himself to the devil.

§ 238.

Vitruvius was first printed at Rome, both in Latin and in Italian, during the life-time of Leonardo da Vinci. There was little this man did not touch—the flying machine, the helicopter, the quick-firing gun, the parabolic compass, the dredge. He died in 1519. Pneumatics—excluding applications of gunpowder—did not revive in Western Europe for another century; its rebirth was signalled by the publication in 1606 of the work of Giovanni Baptista Porta: this was entitled *Magic;* it contained all the data necessary to the construction of the steam suction-pump. In 1629, Branca designed an engine resembling a water-wheel, to be turned by the

impact of a jet of steam upon its vanes. Villeinage and serf-labour were no longer available. The liberty of the individual was to be compensated by the intrusion of the steam-engine.

§ 239.

It is important to recognise the respects in which this was the introduction of a novelty. The force of expansion due to heat was not indeed fully appreciated by Boyle, forty years later, as we have seen; Hooke, too, was much interested to find that he could burst a closed bladder by holding it in front of the fire. It is probable that Boyle saw no essential difference between melting pitch, under cold water, with his burning glass, and with the same object heating litharge or minium, through the surface of a closed glass vessel, which burst. Boyle, of course, was unwittingly preparing oxygen, a fact which may be correlated with Hales' remark, a century still later, that the explosive force of gunpowder came from the nitre. But here we are dealing with a still earlier outlook, and with an epoch in which Bacon was explaining the force of gunpowder as the force of its flame, an epoch in which Van Helmont was writing about "gas sylvestre". The Bacon quotation is in § 144.

So also Shakespeare, where Romeo asks for poison of such nature "that the trunk may be discharged of breath as violently as hasty powder, fired, doth hurry from the fatal cannon's womb". Practically, the coming of the steam-engine was the substitution of heated water for gunpowder, and of the piston for the bullet. Other contributors to the making of the piston were the rammer of the gun, the bullet-on-a-string of the pop-gun or the wad in the rocket, and the disc of the chain-pump—to

which steam-power was first applied. Thus the earliest type of piston may perhaps be recognised in the feathered dart of the primitive blow-tube or sumpitan.

§ 240.

The chain of buckets called "The Egyptian Wheel" was used in the Eastern wells, and, by the time of Ctesibius, had probably developed into the chain of valved vessels which suggested the force-pump. In English mines, it consisted at first of an endless chain with oblong wooden buckets attached at intervals. Each bucket arrived at the top, discharged its water into a trough and descended once more into the well. In its improved form, the endless chain carried discs instead of buckets; in ascending, the chain passed up through a column of tubes or pipes, which the discs smoothly fitted, thus carrying the water above them to the surface. In either case, the chain was worked from a water-wheel, or, where that was impossible, by horse-labour. The horse walked a circular path, thus rotating the great drum which worked the chain, and the horse was superintended by a youth. This was the nature of George Stephenson's first employment in a colliery, and he thus provides an astonishingly close connection between the ancient and the modern. It was a similar milling arrangement that was projected into the sky-myth. A device of this kind was also in use in the Cornish tin-mines, worked largely by owner-miners, where the pits were constantly being flooded. Savery was connected with these, and his engine was built with the purpose of superseding the horse by an engine of much greater power. In the history of the steam-engine, he seems to come fourth.

About three years before Bacon's death, Solomon de Caus, in a work entitled *Les Raisons des Forces Mouvantes,* plays with the idea of a steam pump. Forty years later, the Marquis of Worcester, bored by his imprisonment in the Tower, philosophised on the rattle of the lids of cooking-pots to such purpose as to invent what he called "A Fire-Water Work". He filled a piece of cannon with water, stopped it up and put it on a fire. Then he made a sequence of similar bombs ending in a vertical tube, and found that by rarefying one vessel-full of water by fire, forty times as much cold water might be squirted forty feet high. In 1681, Boyle enlisted Papin, a refugee from religious persecution, and seven years later began those researches which entitle Papin to be called the inventor of the Atmospheric Steam Engine. He expended great labour and ingenuity on the adaptation and improvement of the first Free Piston Engine, which was made by Huyghens in 1680. In this device, gunpowder was exploded within the cylinder when the piston was at the end of the out-stroke, and the gaseous products escaped through a pipe. When the escape had ceased, the pipe was closed; and the continued cooling of the remaining gases formed a partial vacuum which sucked the piston back again into the cylinder. This in-stroke pulled a cord which ran over an arrangement of pulleys. In 1690, Papin tried steam, chiefly because of the dangers encountered with gunpowder, which were supposed not also to reside in steam. Water was placed on the base of the cylinder and heated; the "block, or piston" was pushed up by the steam, the fire removed, and the piston allowed to fall back into place slowly, doing work as it fell. Papin was never satisfied

with the vacuum obtained, the pressure never falling below one-fifth of an atmosphere.

Savery's engine was published in 1702, under the title of "The Miner's Friend, an Engine to raise Water by Fire". Its main innovation was the use of a separate vessel or boiler. It was adopted by only one mine, though it was used for the supply of water to various parts of many great houses and gardens. The next engine, however, that of Newcomen and Calley, was a great commercial success. The first to be sold was installed in 1711. The steam was admitted to the cylinder, cold water was sprayed on its sides, the piston was sucked in, the pump-rod raised and the operation repeated. Then the unusual activity of an engine which had developed a defective piston led to the use of the rose-head piston which sprayed water inside the cylinder, the application of water from without being thereafter abandoned. The various cocks were at first turned by hand, but the ingenuity of a boy attendant, Humphrey Potter, led to their being operated by the periodic motion of the beam.

§ 241.

Watt's attention was enlisted when a student. He had toyed with the idea of applying steam to wheel-carriages, but to no purpose. Then in 1763 his professor asked him to overhaul a small model of Newcomen's engine. This started a train of thought which led him to realise that the cold condenser must be separated from the hot steam cylinder. Eleven years later, in conjunction with Boulton, he was making at Birmingham engines that used only one quarter the fuel required for the

engine of Newcomen. The idea of rotary motion returned, and he made a model employing what he conceived to be the simple and ancient idea of the crank arm; the notion was stolen and patented, but he was able to create a number of other means of converting linear to rotary movement. In 1782, he patented a contrivance for making such movement continuous. This was the crowning improvement: he had arranged to produce a vacuum alternately on either side of the piston at the same time as the other side received the force of the steam. Watt's engine was no longer limited to the mechanical see-saw operation of the pump-beam; it entered every field of industry. It was the final and total eclipse by Scotland of the genius of the West Country for engineering.

§ 242.

Watt was greatly helped in his later work by the skill of Murdoch. The Birmingham firm engaged this man in 1777 at the age of 23, when he had already constructed a primitive bicycle, and sent him to Cornwall to supervise the working of one of their engines. This was too tame a job for a man who built his own lathes, for a man who was the son of the inventor of toothed bevel-gearing. Not only, as we have seen, did he make coal-gas; he constructed a model locomotive. It stood about 14 inches high and was 19 inches long. He made it draw a model wagon round the floor of his Redruth lodging, and, one night, tried it on the smooth surface of the church drive. The tale of the retreat of the local clergyman has often been told. He swore that he took it for the devil in his proper person; but apparently he did not test this theory by resisting it. Murdoch had

indeed been very foolish: no witches were executed in Great Britain after 1722, but a Bavarian was executed in 1775, a Swiss in 1782 and two Polish women in 1793; and such executions are still justified by literary Roman Churchmen of the twentieth century. Lynchings by the superstitious mob happened long afterwards. The students of the new "pneumatic" chemistry were being subjected to the wildest charges, and Boulton, as he thought, by great good fortune, managed to prevent the patenting of Murdoch's invention. It was not Murdoch, therefore, but Murdoch's pupil, Trevithick, who in 1802 constructed the first English locomotive. Across the Channel, things had gone no better: Cugnot scalded a distinguished personage at a private view, and ended his days in prison.

§ 243.

In steam locomotion, the novelty was again in the source of the power, for there were horse railways already. Trevithick exhausted the spent steam through the chimney, but can hardly have appreciated the importance of this arrangement, for he supplied bellows for blowing the fire. However, his first model, though it showed a safety-valve in the drawing, did not possess one and it suffered the consequences. His next locomotive, "Catch Me Who Can", overturned through the breaking of a rail, upon which, his means exhausted, Trevithick deserted the subject. They used his drawings, however, at Wylam Colliery, to produce the famous "Puffing Billy". At a neighbouring pit, George Stephenson was using his leisure in learning to read and write so that he might study the engines of Boulton and Watt. He became known as a very skilful artificer in

the treatment of recalcitrant engines and in 1814, entirely by his own labours, he finished his first locomotive, the "Blucher". At first the locomotive was more costly than the horse, and it is definitely to Stephenson's consciously purposive idea of blasting the waste steam through the chimney of the furnace that the establishment of the steam-locomotive is due.

Smiles quotes Stephenson as prophesying a day "when railways will supersede almost every other method of conveyance in this country—when mail-coaches will go by railway and railroads will become the great highway for the King and all his subjects, when it will be cheaper for a working man to travel upon a railway than to walk on foot". Of railways as electrified, this will probably remain true, even if *railways* be unusually extended in meaning to cover the trams; for here also was the same march of "progress", the horse-trams giving place to the appalling filthiness of the steam-car, to be ousted in turn by the elegance of the modern electric vehicle.

§ 244.

The progress of flight atones for what it is hoped may prove only the temporary use of high roads, city streets and ramblers' lanes as the laboratories of the internal combustion-engine. Certain early inventions which have been called internal combustion engines were also really steam-engines employing steam substitutes, the energy of the explosion being used simply to provide gases at high pressure. Such were those of Lebon (1799) and of Brayton, seventy-four years later, the latter having the advantage of the considerable progress which had been made during this time in the building of real

gas-engines. Lebon supplied gas and air from separate compressing-pumps to a combustion chamber, where the gases were fired. The products then passed through distributing valves to the motor cylinder.

In the Brayton engine, the charge of gas and air was drawn into a compressing pump on the outstroke of the piston and compressed, by its return, into a receiver. It was now at about sixty to eighty pounds per square inch above atmospheric pressure. It was ignited as it entered the motor-cylinder from the receiver, a grating arrangement preventing the flame from being propagated back into the supply. At a predetermined instant, the gas was cut off, so that as the piston moved on to the end of its stroke, the flame-products expanded nearly to atmospheric pressure. The weak point in a very smoothly working engine was the diaphragm grating. It consisted of wire-gauze reinforced on both sides by a perforated plate. A by-pass flame impinged upon this continually, even while the ignited gases from the receiver were not entering the cylinder, so that the gradually burned gauze, no doubt broken occasionally by untender cleaning, always ended by allowing flame to light back through it into the receiver. In the final form, air only was forced into the receiver, taking up its fuel, a light petroleum, as it passed through the grating, in which there was now a groove, filled with felt; the petroleum was mechanically sprayed upon this felt by an atomiser.

§ 245.

A second way of employing the energy of a gaseous explosion is to displace a piston which is free, the work being performed while the piston returns to its initial

position under the influence of its own weight and the partial vacuum following the combustion. Such were the engines of Huyghens, which, as we have seen, suggested the first steam-engines, of W. Cecil (1820) and of Samuel Brown (1820-30), culminating in that of Barsanti and Matteucci (1857), the principle of which, combined with untiring attention to detail, yielded, ten years later, the famous engine of Otto and Langen. The work of Huyghens and of Papin has been described, and the similar proposals of Hautefeuille were probably not pursued. Two of the engines described by Cecil in his paper of 1820 were machines of this type, the first employing gunpowder, exactly like Huyghens'; the second substituted hydrogen, and this worked continuously, exploding with perfect regularity at sixty revolutions to the minute.

In the cycle of operations in the Brown engine, a valve-cover on the top of the cylinder was raised and lowered; while it was off, the cylinder being open and full of air, a jet of gas, ignited at a cock in the base of the cylinder, formed a flame which completely filled the cavity; the valves were now shut, the cover lowered, and a jet of water entered, cooling the hot gases. For good continuity of power, at least three engines seem to have been required; such an arrangement in 1825 drove a carriage up an incline of 10 in 107, and in 1827 a test satisfied the Admiralty that it would drive a paddle-boat, thirty-six feet long, at the rate of seven or eight miles per hour. In the later engines we have mentioned, the return of the piston communicated power to the shaft by the device of rack and pinion; a pawl and ratchet device freed the piston for its upward movement and

trapped it in its descent; cams on the power-shaft determined at what instants in each revolution the valve-movements should occur, and in this manner also the igniting spark at the foot of the cylinder was regulated. The economy of the Otto and Langen was such that its consumption was less than half that of the contemporary real gas-engines for the same output of power. It was ugly and noisy, but it sold in thousands.

§ 246.

The third way of utilising the mechanical energy of the explosion is to allow it to act directly upon the piston. Such is the mode of the real gas-engine, first employed by Robert Street, in 1794. The modern non-compression system closely follows the proposals of W. L. Wright (1833); and William Barnett, the inventor of the first adequate ignition device (1838) was the author of the idea of compressing the gases before they were fired. Engines driven by a charge initially at atmospheric pressure were also produced by W. Cecil (1820), A. V. Newton (1855), Lenoir (1860 and 1885) and Hugon (1865). Compression was adopted, after Barnett, by Schmidt (1861), A. Beau de Rochas (1862), C. W. Siemens (1862) and by Otto, whose "Silent" engine marked an epoch.

Like the first steam-engines, the first gas-engines were applied to working the lever of a pump. Street's method was to introduce a few drops of turpentine into the cylinder when the piston was at the end of the instroke. The cylinder was supported over a fire, so that the air, drawn in by the outstroke, took up the turpentine as vapour and formed an explosive mixture. Flame was

now applied at a touch-hole, and the last portion of the outstroke, that portion which performed the work, was completed under the thrust due to the combustion. During the free return of the pump lever, the work of the piston brought everything back to initial position, so that the action of the engine was continuous.

In Wright's engine, the gas and air were supplied from separate pumps through two reservoirs at a pressure which was necessarily at a few pounds above that of the atmosphere. They entered domed spaces at the two ends of the "cylinder", partly displacing the previous contents, and were ignited as the piston crossed the dead point before the outstroke. The explosion pushed the piston to its extreme limit, the exhaust valve opened, and the return stroke of the piston then discharged a large proportion of the products of combustion. The ignition was again managed by an external flame at a touch-hole.

A. V. Newton's patent describes a form of ignition which came into use about thirty years later, and was proposed also by Drake. The mixed charge, admitted at atmospheric pressure, was ignited when the passage of the piston uncovered a recess in the wall of the cylinder; for, projecting into this recess from the exterior, was a thimble-shaped hollow of hard-cast iron, kept at red heat by a blow-pipe flame.

Lenoir's contribution was the fly-wheel. A portion of the energy stored as the angular momentum of this heavy wheel, keyed to the power-shaft, moved the piston forward during the first part of the outstroke which drew in a charge of gas and air. Then, the valves having been shut, explosion was occasioned by an electric spark, and this propelled the piston to the end of its stroke. The

inertia of the fly-wheel now sent the piston on its return journey or instroke through the cylinder, sweeping out the products of the combustion. This engine proved equal to driving an experimental road-carriage, and was also successfully applied to one of the Seine pleasure-boats on the route Paris-Charenton. In the latter example, it is of historical interest that the fuel was not gas, but a light petrol. There was a good deal of engine-trouble which appears to have been due mainly to bad lubrication, for the piston sometimes reached even red heat and prematurely fired the incoming charge.

Hugon's invention was similar, but he used a mode of ignition closely imitating that of Barnett, whose name brings us to engines employing pre-compression of the gas-mixture. It was Barnett who introduced the modern system wherein this was accomplished by the return movement, or instroke, of the piston itself. In all his three engines, too, the ignition took place when the crank was crossing the dead point, so that the piston received the push of the explosion practically throughout the whole outstroke. Barnett's igniting cock was a hollow plug, surrounding a small gas-jet and rotating freely through a gland in the shell of the cylinder; it was cased in a jacket having an open port on which there impinged an uninterrupted flame. The small interior jet of gas was ignited when an aperture in the hollow rotating plug coincided with the port in the jacket. The momentary exposure to the exterior being concluded, the cavity of the plug communicated with the interior of the cylinder, the gas-jet made adequate contact with the explosive mixture and was turned off as the communication closed, the explosion occurred, and the cycle of operations might be repeated indefinitely.

In 1861, Schmidt recommended the use of compression-pumps, to be worked by the gas-engine itself, which should bring the charge to a pressure of three atmospheres before ignition. Million's first engine exactly exemplified this idea. "Non-compression engines", he states, "are very large in proportion to their power, whereas these engines will exert great power in proportion to their size". He refers imaginatively to the space occupied by the compressed charge as "the cartridge". In the following year, Beau de Rochas advanced various theoretical considerations from which he concluded that the greatest economy of working would be realised by the following cycle of five operations: suction during an entire outstroke, compression during the following instroke, ignition at the dead-point, expansion during the outstroke, and sweep-out of gaseous products on the instroke. Using the recommendations of this pamphlet, Otto produced in 1876 the "Otto Silent" engine, now long known all over the world. Thus the real gas-engine was established on a firm commercial basis, and, in 1890, when this patent lapsed, nearly all engineers adopted the Otto cycle.

§ 247.

Meanwhile, research continued. Lenoir, in his engine of 1885, adopted pre-compression, and reduced his consumption of fuel by 75%. The engine best known as the Clerk Cycle engine was the first to give an impulse for every revolution where the exhaust discharge was timed and controlled by the motor piston only. Other engines were built by Robson, Atkinson and Körting. Daimler tried his first motor-bicycle in 1886, and ran his first motor-propelled car in 1887. About this time too

his engines came into use to drive barges on the canals of the continent. We cannot detail here the developments which enabled the internal combustion engine to challenge steam both on land and sea and culminated in the modern commonplace of flight. So rapid have they been that the enormous generation of traffic has not been confined, like the steam locomotive or the electric tram, to prepared tracks and trained drivers, but, in the hands of private owners, has been permitted not only totally to destroy the comfort of the public roads and gravely to interfere with public services but also seriously to undermine the public confidence and safety. It appears to be common form to mount the almost kerbless side-walks if by so doing a collision in the roadway may be avoided. "This is Safety Week" exclaimed *The Observer,* in its issue of 18th May, 1930, "but nothing less than a Safety Year seems to be of much use to us. Official papers of the week show that on each day for the first quarter of the year three persons were killed and 127 injured—in London alone. Last year's totals of killed and injured in London were 1,383 and 56,321. For the whole of Great Britain there were 6,696 killed and 190,917 injured.

"During the two and a half years of the South African War the total British loss in killed was 5,774. In the same period, on the figures given above, we may expect to lose 16,740 lives in street accidents. It looks as if it were more dangerous to cross the street in this island than it was to face the Boer rifles. And we take it all as a matter of course". These numbers have since increased, and even the London Policeman, that sacred rock and bulwark of order, is disabled to the tune of several hundreds per year.

§ 248.

The heavy-oil engine was introduced by Priestman between 1885 and 1890. He employed a spray vaporiser and electric ignition. The machine of Stuart Ackroyd applied successfully for the first time the idea of vaporising and igniting oil at the hot walls of the combustion chamber. In the Diesel engine, air alone is compressed to such a point that its temperature is higher than the range of ignition-temperatures of the heavy oil. The oil-spray, which ignites, therefore, as it enters, is injected by air at higher pressure still.

§ 249.

At first sight it would seem that the push suffered by the piston in the ordinary gas-engine should be easily calculable. One would start by writing $T = Q/c$; that is, the temperature should equal the heat energy available divided by the specific heat of the gases heated. But we do not know the exact chemical equation releasing the energy, nor whether it is homogeneous and complete; nor do we know the specific heats of the gases: the amount of heat necessary to raise unit amount of gas by one degree at atmospheric temperatures is not the same at the temperature of the flame—and, in any case, what *is* the temperature of the flame? T, then, thus calculated, is a very doubtful result. From this dubious value, we are now to find the pressure, using the laws of Boyle and Charles and the further baseless assumption that the gases behave as perfect gases. There is a great discrepancy between the values obtained by arithmetic from the data described, and the values found practically. This "Lost Pressure", as engineers have named it, is

partly accounted for by the fact that the gases are losing heat to the wall during the time that pressure is being applied to the piston, and this loss is greatly intensified by the fact, discovered by Clerk, that the charge is turbulent, the spray entering the cylinder at the rate of some 70 to 80 miles per hour. The flame is formless and atomised, and its actual area of surface must be enormous.

§ 250.

We turn now to the future of the mechanical application of power. Sturgeon's invention, in 1825, of the electromagnet led, some twenty years later, to Faraday's invention of the dynamo. Before the end of the century, steam-engine, gas-engine and oil-engine alike were busily engaged in rotating electric generators. For this new form of power, fatuous as the ideas of "splitting the atom" and "power-transmission by radiation" may be, has superlative advantages. It is in fact transmissible and accurately controllable over immense distances, it may be used over large areas or it may furnish an answer to the ancient query as to how many "spirits" may stand on a pin's point, it is readily convertible with little waste into every other form of energy, it is produced without bye-products which vitiate the atmosphere and destroy healthy vegetable and animal life. It may be stored. In electricity, non-thermal, immateriate and pure, the animating principle of our history comes at a whistle to its bit and bridle.

§ 251.

"Yet some footsteps of the ancient vice shall remain", says the Eclogue, "to urge men to the sea in ships", but it has dawned upon the world like an uncertain sunrise

that we have come now to a point where, except for travel on the sea and through the air, steam and oil are no longer necessary. "Our fire is Water", wrote the alchemists, whose superficially most extravagant statements seem ultimately to exact a literal fulfilment. So, for many generations, men conceived electricity as a fluid. Now, furthermore, we are ready for an actual return to the water-wheel, drawing thence a new current in an ionic stream. The torrents famous in future history will be not the Ister, the Euphrates, the Tiber or the Marne; they will be the Gyndes, which Cyrus humbled, the Pactolus, which carried down gold-dust to Sardis, they will be the first great electric generators, the Niagara, the Victoria Nyanza and the Shannon. Yet the power in Water is not of itself. It is a thing of radiance and immateriate virtues, a magic of the Sun and Moon.

Only a curable myopia hides from us this "Open Entrance to the Closed Palace of the King": to adopt water-power sectionally is to accept the risk of a spurious defeat in the vicious competitive strain of modern existence. The spuriousness alike of the defeat and of the selfish advantage is beginning to be realised. There is no undue pessimism in concluding that the incentive to advance must be self-interest, and fortunately self-interest itself must eventually force the co-operation necessary to the wholesome collection and rational employment of power. Doubtless our grandchildren, living under the clear skies and thriving in the pure air of bright industrial areas, will regard the present age with the same appalled astonishment as we feel in recollection for the old gas-works and the flying cinders of the steam-driven trams.

§ 252.

Hardy wrote shortly before his death of the modern

> barbarising of taste, the unabashed cultivation of selfishness in all classes, the plethoric growth of knowledge simultaneously with the stunting of wisdom, a "degrading thirst after outrageous stimulation"

and saw the threat of a new Dark Age. But Juvenal wrote all this. Have we seen no progress since Juvenal? In truth it was little perceptible until the last two hundred years. In truth, nothing in the Holy Office of the Inquisition differed greatly from the killing of Achæus by Antigonus: both took place under the Sign of the Weeping Crocodile. But the curve of growth is a strange curve. The leaven propagates, but, except under the microscope, no one can tell that it is also actually multiplying. It lies along the axis, hugging the zero; apparently there is no growth at all; but each new cell is growing at the same rate as the first did, and so from a rate of two and three we find a growth to thirty, sixty and a hundredfold, until at last the curve rears and shoots up like the fiery serpent of November or the Maya snake of Time, into the Infinite. Already it may be said with certainty that kindliness and good will have established their supremacy. The future is to them. And indeed it would be disconcerting if the coming age of physical light and well-being were to coincide in time with a permanent loss of human goodfellowship. There appears to be no evidence that humanity's gradual synthesis has suffered more than a temporary check. New methods of transport and communication are building a magnificent arterial and nervous system for the new body politic. They need only function in their fullness to create a unitary organism, feeding and housing a communal soul.

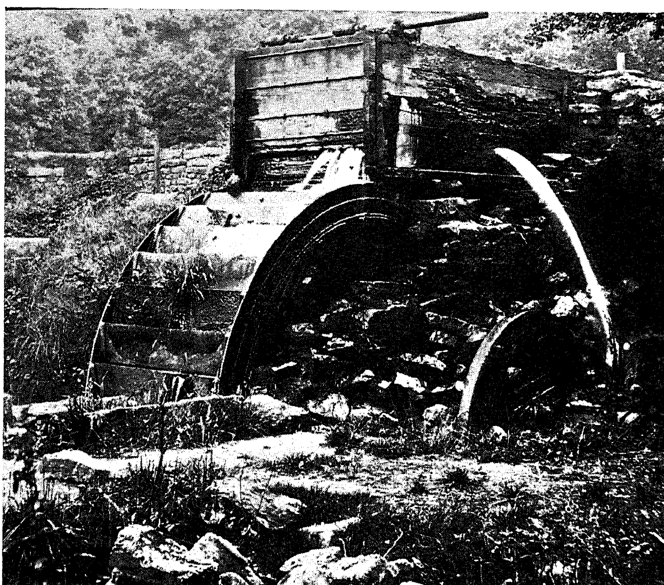
Emotionally also we stand upon the threshold of new things. Like Thucydides' Athenians,

> "We have left behind us a city that was a city no longer and staked our lives for a city that lives only in our own desperate Hope".

Yet not quite desperate. As the Earth shrinks, there are signs of an awakening consciousness that no man liveth to himself, that it is the oaf that fouls the air, that offends the sight, that obtrudes the noise upon the healing balsams of the silence. The cruel religious systems, too, with their sanctions, their rewards and punishments, their priests, their altars, their fetishes and their taboos, are dying with the death of the fear of an external cruelty. They spread the mist and murk of their fermenting stagnancy along the sky, but we fear them no more. Men read in Polybius of an ulcer of the soul and in Lucilius of a dropsy of the mind, and begin to wonder whether Evil also is not but an intellectual rickets, an indigence of nature, whether generosity and kindliness are not the simple positive expression of the positive emotional energy. Force rules the world still, but what a force! It is the butt of fools, but to the serious mind it is the immortal Wonder. The biographer pauses in amazement, visited by some vivid realisation of the immeasurable power that is the spirit of so many springs of noble and heroic action. The mathematician, radiant for a moment in some rich personal experience, argues back unconsciously from the microcosm to the Cosmos. He halts among the hesitant hieroglyphs of his differential equations to wonder at the inevitable projection of the ebullient beauty in his mind upon the rediscovered firmament. Does he then fear to over-estimate the tenderness and beauty of the thoughts of God?

A FIRE THAT IS NOT BLOWN

("And the Spirit of Life was in the Wheels.")



He paweth in the valley.
He bindeth up the Waters.
He hath compassed the Waters with bounds.
He weigheth the Waters by measure.
He walketh in the Circuit of Heaven.

THE END.

I have at length cast in my Mite into the vast Treasury of a Philosophical History —Hooke on his *Micrographia*.

ACKNOWLEDGEMENT.

MOST of the facts correlated in this volume come direct from the familiar classics (readily accessible among our "Bohns" or "Everymans" or "Loebs" or "Broadways") which I have named in the text. For the student's convenience and interest, particulars of many others are added in the list below. As to modern writers, I am conscious most of my debt to Mr. A. E. Waite and to Sir E. A. Wallis Budge (though they must not be held responsible for any erroneous deduction from their facts); but, so far as I know, I have not excluded any recent book which has helped me with any contributory information.

My debt to the best modern newspapers is considerable. An example is an article in the *Observer* by Professor E. N. da C. Andrade; and there was a correspondence on the best fuel for wood-fires in the pages of the *Times* that led me into one of the most enjoyable of researches. I have learned also, as never before, to appreciate the Thirteenth Edition of the *Encyclopædia Britannica.*

A special note should perhaps be made on the books about Witchcraft. The best of all is that of Coulange, who, however, confines himself to one aspect of the problem. Wickwar provides a general introduction, sane, clean and simple, though essentially bluff and hearty and popular. In Sir Walter Scott, to the interest of his subject is added the interest of his own attitude, a grave

personal humanity sternly kept in check by a pious regard for Hebrew literature. This traditional reverence does not, as might appear, reach its limit in the *Dæmonologie* of James I: we have the works written and edited by our contemporary, the Reverend Montague Summers; these are no less valuable for their accurate reproduction of the medieval outlook than for their revelation of the present unchanged and unchanging mentality and attitude of a powerful Church.

The reproduction of plates has been acknowledged in every case, but I have also to thank the Institution of Mining Engineers, the Safety in Mines Research Board, and *Fuel in Science and Practice* for the actual loan of blocks. Mr. Albert Tew has revealed himself as a prodigy of patience in helping me to compile the index. Many of my friends have been kind enough to read the book in various stages of its growth. Mr. Walter de la Mare out of the natural goodness of his heart has also done me this very great service. I am deeply grateful to them and to him.

* * * *

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INDEX

TO THE NUMBER OF THE SECTION.

[*Chapter headings are scheduled in the sections immediately following them.*]

INDEX—*continued.*

(2nd Edition)

The Poems of Edna A. Kahla

with an introduction by

OLIVER C. de C. ELLIS.

Press Reviews:

We have selected, for reprinting *in full,* two articles devoted to these poems. The first, that of the *Times Literary Supplement,* has been chosen because of its authority; the second, that of the *Methodist Recorder,* because the poems are so obviously the work of a Roman Catholic.

[The Poetry Lovers' Fellowship has no interest or object in its publications except to set its seal upon work of superlative merit.]

PRESS REVIEWS OF THE FIRST EDITION OF THIS VOLUME.

A True Dreamer

(*Times Literary Supplement*).

This is the first publication of The Poetry Lovers' Fellowship, whose ambition, in Mr. Ellis's words, is "to reach, at one end, the poetry-lover and, at the other, the poet." In the poems of Miss Kahla it has certainly realized half its aim. Many of them speak explicitly of dreams; but the dreams of which she writes are not day-dreams, unless by day-dreams is implied that shedding of worldly wisdom and recovery of true innocence which she celebrates in "The Return." Still less are her dreams nostalgic. They are true evocations of the unconscious, of that inward reality of which she writes:—

> And gathering the darkness to my heart,
> I sought in the stillness, silent and apart.

It is not, however, a region of repose. And, characteristically, she speaks in one place of "the first lull that follows the first dream." She finds death in it as well as life, as she finds pain at the heart of beauty. And this dream mood, with its ecstasy and its menace, is implicit also in her wakefulness. It presses upon the conscious mind:—

> There is a sigh out there
> Where silence was before,
> Someone climbs the stair
> With soft feet on the stone,
> Pauses, and watches there
>   Stealthily, at the door.
> And stirs, and sighs in pain,
> And pleads again and again
> Let me come, let me come in!
> And with a furtive hand
>   Opens the door.
> The place grows chill with shadow
> Where sunlight was before.

It would be wrong, however, to suggest that Miss Kahla is obsessed by the unconscious. Her virtue as a poet lies in the fact that her love of daylight beauty and the radiance of many lands and places which she has visited has its roots in a reality of which the apparent is a transient expression. And it is because beauty vibrates to her from such depths that at times she finds it almost unbearable. As she writes of chiming bells in "Burden of Beauty":—

> Make not the night unbearable
> With music and its moaning tide
> Of beauty, not to be denied—
> Make not the night unbearable!
> Ever throughout your song 'twould seem
> The passion of the swelling wind
> Returns again, returns again—
> Fast as our hearts deny their dream,
> Unbearable Beauty comes again.

Nature, too, knows her "wild tenacity," her sense of estrangement from, and her desire for identity with, the life that stirs in the interlacing leaves. But for her the greatest of all dreams is "the unforgotten dream" of Calvary. In her own words:—

> Strange new journeys lead us back again
>   To one dark hill.

And here again, because her dream is both profound and personal, she invests, in "Crucifixion," or "Poet's Calvary," this "symbol of love and loss" with a new reality.

A Modern Religious Poet

(*Methodist Recorder*).

The Poems of Edna A. Kahla (5s. net) is announced as the first volume of the Modern Poets Series, published by Messrs. Simpkin Marshall Ltd., under the auspices of the Poetry Lovers' Fellowship. One of the objects of this society, as set out on a fly-leaf of the volume, is "to publish such original work as seems to be of altogether unusual merit, so that the imprint of the Poetry Lovers' Fellowship upon a volume will indicate that the contents are of the highest poetic value and their publication beyond any possibility of criticism." If the society succeeds in discovering writers whose work reaches this exacting requirement, it will be a welcome guide amid the rather bewildering experiments of the present poetic revival.

It may be said at once that this first venture inspires confidence. Miss Kahla's work is certainly modern, but most assuredly it is also poetry. She experiments with verse forms, of course—that is almost inevitable nowadays; but her metrical inventions are invariably musical and often exquisite; she never tortures language, and she reveres the beauty of words too well to employ them for self-display. Reverence, indeed, is the note of all her work; whatever her theme, it absorbs her and she loses herself in it. In this respect she is consciously at odds with the spirit of modern egotism, from which, in so far as it threatens her, she recoils with dismay:—

> When comes abandonment to set me free
> From the relentless me,
> Stronghold whose walls are self, and self, and self?

Writing from Paris, her thoughts turn to the simplicity of English Aprils and the fields:—

> Whose flowers are innocent of their rarity,
> Steeped though they be in beauty to the tip
> Of all their delicate petals' purity.

This is one of the directions in which she seeks freedom from self—through "abandonment" to the beauty of things whose loveliness is a secret that must be searched out, since it is hidden from themselves.

In one poem, "The Estranged," she thinks herself into the life of natural things in order to render them conscious, as it were, of their unrealized strength and beauty. It is notable that, though she knows other lands, she is more attracted by the retired and undemonstrative beauty of English scenery:—

> Oh, dreaming Italy is golden still,
> And Southern France, with all her flaming flowers,
> Is all too bright and all too wearying
> With changeless sunlight through the changeless hours.

All the poems that deal with English themes have the fairy-touch, the sense of natural magic, which is the familiar miracle of English nature poetry. But there are others in which another note is struck, not of magic but of religious mystery. Much of Miss Kahla's work has appeared in "G. K.'s Weekly," and in the opening poem of this volume she gives new shape to a devout fancy with which Mr. Chesterton played suggestively in one of his earlier novels:—

> Still shows the rood upon our darkest door,
> August, austere, symbol of love and loss;
> Our narrow windows frame against the sky
> The cross, the cross, and the cross.

The repetition here, it may be noted, answers to the threefold "self" already quoted from another poem; and though it is but a verbal coincidence, it does actually symbolise the solution of a problem. For the final escape from self which Miss Kahla craves—like so many of us—is provided, not by nature, but by religion. In these poems there is the unmistakable utterance of a personal faith and even if the accent be unfamiliar, the spirit is one with which a generous believer may well be glad to have fellowship.

W. Handley Jones.

[The volume is published for the Poetry Lovers' Fellowship by Messrs. Simpkin Marshall at 5/- nett. The type is handset. Otherwise the usual P.L.F. format is observed.]

THE POETRY LOVERS' FELLOWSHIP

WHATSOEVER THINGS ARE LOVELY, THINK ON THESE.

President - LASCELLES ABERCROMBIE.

The Poetry Lovers' Fellowship is concerned for "poetry" which it conceives to be the expression, in any form whatever, of fine creative thought: but the thought expressed is greater than the expression, and it is this thought which we spell "Poetry."

Members of the Poetry Lovers' Fellowship seek a right view-point where they may find the purpose of Life focussed. They think that the old philosophical ideal of Oneness, Wholeness and Health may then come within our range.

Seeking a practical path to this ideal, the Poetry Lovers' Fellowship has become an association of readers, writers and interpreters, of poets of music—like our great composers—, of poets of science—like our great research men—, of poets of conduct—for the race of heroes has not perished—, of poets of literature and the stage—like the members of the constellation of eminent writers and interpreters enumerated in our list of honorary members; it has become, too, a federation of literary, scientific, artistic and philosophical societies, each of which follows unhampered its own genius without any loss of its complete independence; it is indeed a manifestation of an open conspiracy towards the appreciation and creation of the best in life, literature and discovery.

J. W. Northend Ltd., Printers, 49 West Street, Sheffield